CHAPTER 8

RESEARCH FINDINGS AND DISCUSSION OF RESULTS

8.1 EVAPORATOR

(I). COMPARISON BETWEEN CEC AND CEC \[M\]

It is clear by the graphical output in Fig 8.1, that the reliability of the evaporator in both the cases before and after modification is fairly different. It is so because that the concept of redundancy can be applied in the case of evaporative coil regarding its choking or blockage. This problem of blockage comes when there is any outer impurity exists in the evaporative coil. This impurity does not pass through the narrow hole of the coil because the diameter of the coil becomes small enough. If it is so the flow of refrigerant decreases or totally closed. This type of defect affects very much the entire cooling system. Due to this type of blockage, the needed temperature is not maintained in the evaporator.

Such type of defect can also be removed by proper maintenance of machine by defrosting etc. The probability of blockage can be brought to zero if a proper
maintenance schedule is made. Such defect does not come frequently. Put another evaporative coil in the spare (standby redundancy) to replace it, when it is damaged suddenly.

It is clear by the observation Table 4.1, of the evaporator that the first complaint regarding blockage in evaporative coil comes between fifth to sixth years. It is hardly 3 in the sample of 216 domestic refrigerators. It happens so because if the system is being used so much then the chances of corrosion-erosion and tear wear also increase. It was happened because for these refrigerators maintenance schedule was not set properly. This observation Table 4.1, is also giving the result that the blockage complaint came regularly every year after a year. The cause of all these was that the duration of application of VCRS was increased and the maintenance schedule was not decided properly.

With the passage of time due to corrosion and erosion in many parts of the system, frozen materials also erode and mixed with refrigerant and start flowing with the system. Through maintenance, if these are not separated from the refrigerant then they make blockage in pipes and coil. So if system grows older in the same way the frequency of its maintenance should also be increased more and more.

(II) COMPARISON BETWEEN LOR AND LOR [M]
Leakage in the evaporative coil is an ordinary problem and this problem occurs more in VCRS. As it is clear from the complaint of the evaporative coil, according to Table 4.1, came from only 1 system among 216 within four years. In this way it was found that 3 complaints within the fifth year, 3 in the sixth year, 1 in the seventh year and 5 in a tenth year etc.

In the Fig 8.2, the calculated values of reliability regarding the leakage of refrigerant for different years are shown. The lifespan of the better performance of refrigerator or its evaporator is assumed for 15 years. In the Fig 8.2, two graphs are shown. One of these two graphs has a large inclination towards the time axis or horizontal axis and another graph appears as a parallel to the time axis. The actual measurement of the reliability of existing systems for its evaporators regarding the leakage of refrigerant is shown in the first type of graph, which appears more inclined towards the time axis. The Fig 8.2 is plotted by the actual analysis of collected data from zero to fifteen years. The other type of graph gives the values of reliabilities for fifteen years after modification or after the implementation of parallel redundancy for evaporator pipes to avoid the leakage of refrigerant or after applying a better maintenance schedule which gives the equivalent value of enhanced reliability from starting to next fifteen years.
After observing from the Fig 8.2, it can be concluded that the more separation at the endpoints of the graph gives the measure of the actual reliability enhanced figure toward the finish of fifteenth years. The slope of the first graph shows the reliability degradation rate with time. Here more slopes towards the time axis indicate that the degradation in reliability is more with respect to time. The parallelism of the reliability graph after modification shows that the reliability degradation rate becomes very slow after the implementation of the concept of redundancy.

After comparing the above two graphs of Fig 8.2, it is found that the reliability degradation rate which was 0.00158 per year previously and decreased to 0.00007 when the modification has been done. These figures indicate the better values of enhanced reliability.

(III) COMPARISON BETWEEN ROE AND ROE [M]

![Graph showing comparative reliability enhancement graphs for ROE AND ROE [M]](image)

Fig. 8.3: Showing comparative reliability enhancement graphs for ROE AND ROE [M]

After an observation of data in Fig 8.3, it is clear that up to the end of the first year the reliability of an evaporator remains 99.69 % without any modification. It continuously comes down remains only 95.45 % at the end of 15th years. So such types of data give a result that frequent problems may occur in the evaporator at the end of 15th years. Therefore it affects the overall performance of a domestic refrigerator.
When modification has been done the reliability degradation rate of the evaporator becomes very low. Form the above graph it is confirmed that the reliability of evaporator becomes near to 99.89 %. This figure of reliability at the end of the fifteenth year confirms that the life and performance both for evaporator are increased after modification. This increased figure of reliability for the evaporator increases the overall reliability of a domestic refrigerator.

8.2 COMPRESSOR

8.2.1 COMPRESSOR (ELECTRICAL): INDUCTION MOTOR

(i) COMPARISON BETWEEN ROCAP AND ROCAP [M]

![Graph showing comparison between ROCAP and ROCAP [M]](image)

Fig. 8.4: Showing comparative reliability enhancement graphs for ROCAP AND ROCAP [M]

Failure of the capacitor is an ordinary problem and this problem occurs more in electric motors. It is clear that the 3 complaints of capacitor failure appeared among 216 within third to the fourth year. In this way only one complaint within the fourth to the fifth year, 7 in the sixth year, 2 in the seventh year and 3 in the tenth year and so on.

In the above graphs in Fig 8.4, the reliability values are shown regarding the failure of capacitors for different years. The lifespan of the better performance of refrigerator or its compressor due to its electric motor is assumed for 15 years. In the
above Fig 8.4, two graphs are shown. One of these two graphs has a large inclination towards the time axis or horizontal axis and another graph appears as a parallel to the time axis. The actual measurement of the reliability of existing systems for its capacitor regarding its performance is shown in the first type of graph, which appears more inclined towards the time axis. Here, the Fig 8.4 is plotted by the actual analysis of collected data from zero to fifteen years. The other type of graph gives the values of reliabilities for fifteen years after modification or after the implementation of parallel redundancy for the capacitor. Therefore the Fig 8.4 gives the equivalent value of enhanced reliability from starting to next fifteen years.

After observing from the Fig 8.4, it can be concluded that the more separation at the endpoints of the graph gives the measure of the actual reliability enhanced figure toward the finish of fifteenth years. The slope of the first graph shows the reliability degradation rate with time. Here in the first graph, more slopes towards the time axis indicate that the degradation in reliability is more with respect to time. The parallelism of the reliability graph after modification shows that the reliability degradation rate becomes very slow after the implementation of the concept of redundancy [39].

After comparing the above two graphs in the Fig 8.4, it is found that the reliability degradation rate which was 0.00197 per year previously and decreased to 0.00006 per year when the modification has been done. These figures indicate the better values of enhanced reliability.

(ii) COMPARISON BETWEEN ROCN AND ROCN [M]
Connection means to connect one electrical part into another by wires. Electrical connections are generally done with electric wires. These wires become present into electric motors in several forms. Such as switch wire, connection wire, and binding wire etc. If conducting material of these wires is observed then it is found that they all are made of copper metal. All the conducting materials of wire used in a refrigerator should be copper metal.

Failure of connections is another problem and this problem also occurs more in electric motors. As it is clear by the by seeing the observation Table 5.1, regarding a complaint of connections, it is observed that only1 system fails among 216 within fifth to the sixth year. In this way 4 complaints between 7th to 8th year, 3 complaints between 8th to 9th year, 6 complaints between 10th to 11th year and 2 complaints between 11th to 12th year and so on.

In the above graphs shown in Fig 8.5, the calculated value of reliability regarding the faults in connections for different years is shown. The lifespan of the better performance of refrigerator or its compressor due to its electric motor is assumed for 15 years. In the above figure, two graphs are shown. One of these two graphs has a large inclination towards the time axis or horizontal axis and another graph appears as a
parallel to the time axis. The actual measurement of the reliability of existing systems for its connections regarding its performance is shown in the first type of graph, which appears more inclined towards the time axis. This graph is plotted by the actual analysis of collected data from zero to fifteen years. The other type of graph gives the values of reliabilities for fifteen years after modification or after the implementation of parallel redundancy for connections. Therefore the Fig 8.5 gives the equivalent value of enhanced reliability from starting to next fifteen years.

After observing from the above graphs shown in the Fig 8.5, it can be concluded that the more separation at the endpoints of the graph gives the measure of the actual reliability enhanced figure toward the finish of fifteenth year. The slope of the first graph shows the reliability degradation rate with time. Here in the first graph, more slopes towards the time axis indicate that the degradation in reliability is more with respect to time. The parallelism of the reliability graph after modification shows that the reliability degradation rate becomes very slow after the implementation of the concept of parallel redundancy.

After comparing the above two graphs in the Fig 8.5 plotted for ROCN and ROCN[M] it is found that the reliability degradation rate which was 0.001386 per year previously and decreased to 0.00003 per year when the modification has been done. These figures indicate the better values of enhanced reliability.

(iii) COMPARISON BETWEEN ROTM AND ROTM [M]
The timer in electric motors is often used to control the functioning of compressors. The compressor consumes more electric power when it runs. To save the electric power and also the life of compressor timer is used to control its functioning. The timer is used like a switch which decides the exact closing and opening time of switch for the compressor. It is important for any vapor compression refrigeration system to save energy and life of the refrigerators. Timers are used as a switch to ON or OFF the refrigerator by regulating the working of the compressor.

Failure of the timer is another problem and this problem also occurs more in refrigerators. As it is clear by the by seeing the observation Table 5.1, for a complaint of connections it is observed that two timers of the system fail among 216 within fourth to the fifth year. Similarly, it is observed the 3 complaints between 7th to 8th years, 1 complaint between 9th to 10th years, and so on.

In the Fig 8.6, the calculated values of reliability regarding the timers for different years are shown. The lifespan of the better performance of refrigerator or its compressor with its timers is assumed for 15 years. In the above figure (Fig 8.6), two graphs are shown. One of these two graphs has a large inclination towards the time axis.
or horizontal axis and another graph appears as a parallel to the time axis. The actual measurement of the reliability of existing systems for its connections regarding its performance is shown in the first type of graph, which appears more inclined towards the time axis. This graph is plotted by the actual analysis of collected data from zero to fifteen years. The other type of graph gives the values of reliabilities for fifteen years after modification or after the implementation of redundancy for connections. Therefore the above graph gives the equivalent value of enhanced reliability from starting to next fifteen years.

After observing from the Fig 8.6, it can be concluded that the more separation at the endpoints of the graph gives the measure of the actual reliability enhanced figure toward the finish of fifteenth years. The slope of the first graph shows the reliability degradation rate with time. Here in the first graph, it has more slopes towards the time axis indicate that the degradation in reliability is more with respect to time. The parallelism of the reliability graph after modification shows that the reliability degradation rate becomes very slow after the implementation of the concept of redundancy.

After comparing the above two graphs in the Fig 8.6, plotted for ROTM and ROTM [M] it is found that the reliability degradation rate which was 0.001093 per year previously and decreased to 0.00002 per year when the modification has been done. These figures indicate the better values of enhanced reliability.

(iv) COMPARISON BETWEEN ROINDMOT AND ROINDMOT [M]
After an observation of data, it is clear that at the end of the first year the reliability of induction motor remains 99.55% without any modification. It continuously comes down and exists only 93.47% toward the finish of fifteenth years. So such types of data give a result that frequent problems may occur in the refrigerator at toward the finish of fifteenth years. Therefore it affects the overall performance of a domestic refrigerator.

When modification has been done the reliability degradation rate of induction motor becomes very low. Form the Fig 8.7, it is confirmed that the reliability of the evaporator becomes near to 99.84%. This figure of reliability toward the finish of fifteenth years confirms that the life and performance both of induction motor is increased after modification. This increased figure of reliability for induction motor increases the overall reliability of the compressor or domestic refrigerator.

8.2.2 COMPRESSOR [MAIN]

(i) COMPARISON BETWEEN ROSDVL AND ROSDVL [M]
Fig. 8.8: Showing reliability enhancement of ROSDVL [M] as compared to ROSDVL with time

These valves are located before the head part of Piston. These provide right direction to flow of refrigerants. When the suction valve is opened then the refrigerant enters into the cylinder. Generally, the problem comes in suction and discharge valve due to leakage in the refrigerant. It is so because on the plate of valves carbon or foreign material is deposited or overloading of valve goes very high. By this suction or discharge, the quantity may also go down through the valve.

Suction and discharge valve is used as an inlet and outlet door for refrigerant inside the compressor. With the help of a suction valve, the refrigerant enters into the compressor after absorbing heat from the evaporator. Similarly, the discharge valve sends the compressed refrigerant to the condenser when it opens. Generally, the open type vertical reciprocating compressor is used in domestic refrigerators. The discharge valve opens when a sufficient amount of pressure is reached after compression. The frequent opening and closing of suction and discharge valve effect on the reliability of it. The material of these valves must have sufficient strength regarding heat and hardness.

Failure of suction and discharge valve is a common problem and this problem also occurs more in the compressor refrigerators. It is clear from the observation Table 5.2,
that the complaints about suction and discharge valve came in two refrigerators only among 216 refrigerators, first time between 5th to 6th years. In the same sequence of observation, there are 3 complaints between 8th to 9th years, 2 complaints between 9th to 10th years, and so on.

In the above graphs shown in the Fig 8.8, the calculated value of reliability regarding the suction and discharge valve for different years are shown. The lifespan of the better performance of refrigerator or its compressor regarding its suction and discharge valve is assumed for 15 years. In the Fig 8.8, two graphs are shown. One of these two graphs has a large inclination towards the time axis or horizontal axis and another graph appears as a parallel to the time axis. The actual measurement of the reliability of existing systems for its suction and discharge valve regarding its performance is shown in the first type of graph, which appears more inclined towards the time axis. This graph is plotted by the actual analysis of collected data from zero to fifteen years. The other type of graph gives the values of reliabilities for fifteen years after modification or after the implementation of parallel redundancy for connections. Therefore the above graph gives actual value of enhanced reliability from starting to next fifteen years.

After observing the Fig 8.8, it can be concluded that the more separation at the endpoints of the graph gives the measure of the actual reliability enhanced figure toward the finish of fifteenth years. The slope of the first graph shows the reliability degradation rate with time. Here in the first graph, it has more slopes towards the time axis indicate that the degradation in reliability is more with respect to time. The parallelism of the reliability graph after modification shows that the reliability degradation rate becomes very slow after the implementation of the concept of redundancy.
After comparing the above two graphs shown in Fig 8.8, plotted for ROSDVL and ROSDVL[M] it is found that the reliability degradation rate which was 0.00877 per year previously and decreased to 0.00022 per year when the modification has been done. These figures indicate the better values of enhanced reliability.

Valves are not much costly and its size is also very small. So there should not be any problem in its storage. Therefore to improve its reliability the concept of redundancy is its best option. To improve the reliability regarding valves, here the concept of redundancy has been used.

(ii) COMPARISON BETWEEN ROCNND AND ROCNND [M]

![Graph showing reliability enhancement of ROCNND [M] as compared to ROCNND with time](image)

Fig. 8.9: Showing reliability enhancement of ROCNND [M] as compared to ROCNND with time

Connecting Rod is an important component which converts rotating motion of the electric motor into reciprocating motion of Piston. It behaves like a lever arm. It makes material becomes mostly cost aluminum alloy.

There becomes connecting rod stretch and compress in every stroke of compressors like a cyclic loading and unloading. In this way, pressure and some other factors are only responsible for failure in connecting rod. If this rod is broken then the compressor is totally failed and refrigeration system totally stops its working.
Though the material by which this instrument is made of becomes so powerful that it is not broken by cyclic loading and unloading. But there are chances of failure in it also due to heavy duty or lack of preventive maintenance. The chance of failure of connecting rod is rare phenomena. It does not occur frequently in the refrigerators. Failure of suction and discharge valve is not a common problem but this problem also occurs randomly in more in the compressor of refrigerators after a period of time. Since referring to the observation Table 5.2, the complaint in the connecting rod appears in two refrigerator systems among 216 refrigerators first time between 7th to 8th years. In this way it is observed only 1 complaint between 8th to 9th year and 4 complaints between 10th to 11th years, and so on.

In the above graphs shown in Fig 8.9, the calculated values of reliability regarding the connecting rod for different years are shown. The lifespan of the better performance of refrigerator or its compressor regarding its connecting rod is assumed for 15 years. In the above figure, two graphs are shown. One of these two graphs has a large inclination towards the time axis or horizontal axis and another graph appears as a parallel to the time axis. The actual measurement of the reliability of existing systems for its connecting rod regarding its performance is shown in the first type of graph, which appears more inclined towards the time axis. This graph as shown in Fig 8.9 is plotted by the actual analysis of collected data from zero to fifteen years. The other type of graph gives the values of reliabilities for fifteen years after modification or after the implementation of parallel redundancy for connections. Therefore the above graph as shown in Fig 8.9, gives the actual value of enhanced reliability from starting to next fifteen years.

After observing from the above graphs as shown in Fig 8.9, it can be concluded that the more separation at the endpoints of the graph gives the measure of the actual reliability enhanced figure toward the finish of fifteenth years. The slope of the first
graph shows the reliability degradation rate with time. Here in the first graph, it has more slopes towards the time axis indicate that the degradation in reliability is more with respect to time. The parallelism of the reliability graph after modification shows that the reliability degradation rate becomes very slow after the implementation of the concept of parallel redundancy.

After comparing the above two graphs as shown in Fig 8.9, plotted for ROCNND and ROCNND [M] it is found that the reliability degradation rate which was 0.00138 per year previously and decreased to 0.000028 per year when the modification has been done. These figures indicate the better values of enhanced reliability.

(iii) COMPARISON BETWEEN ROPNR AND ROPNR [M]

Fig. 8.10: Showing reliability enhancement of ROPNR [M] as compared to ROPNR with time

Mostly pistons are formed by the costing of aluminum alloy. To provide them a good strength and high reliability a forging should be done in their inner surface. Pistons made of aluminum alloy have high reliability. These pistons show higher work performance than those Pistons which were made of iron in old days.

The piston ring is used to seal or cover the cavity between the piston and cylinder. The cylinder used in reciprocating compressor should be such as there is no cavity of any type. If there is any cavity between Piston and cylinder then friction may be
increased and due to this heat production would go up. The only work of Piston and ring is filling with the cavity between piston and cylinder and to permit motion as much as possible with minimum forces. The piston ring is made of cast iron.

Failure of the piston ring is a common problem and this problem also occurs more in the compressor of refrigerators. From the data of observation Table 5.2, it is clear that the complaint about piston ring come in two refrigerator systems among 216 refrigerators first time between 4th to 5th years. In this way 2 complaints between 5th to 6th year, 1 complaint between 6th to 7th year, 4 complaints between 8th to 9th year and so on.

In the Fig 8.10, the calculated value of reliability regarding the piston ring for different years is shown. The lifespan of the better performance of refrigerator or its compressor regarding its piston ring is assumed for 15 years. In the Fig 8.10, two graphs are shown. One of these two graphs has a large inclination towards the time axis or horizontal axis and another graph appears as a parallel to the time axis. The actual measurement of the reliability of existing systems for its piston ring regarding its functioning is shown in the first type of graph, which appears more inclined towards the time axis. This graph as shown in Fig 8.10 is plotted by the actual analysis of collected data from zero to fifteen years. The other type of graph gives the values of reliabilities for fifteen years after modification or after the implementation of parallel redundancy for connections.

After observing from the Fig 8.10, it can be concluded that the more separation at the endpoints of the graph gives the measure of the actual reliability enhanced figure toward the finish of fifteenth years. The slope of the first graph shows the reliability degradation rate with time. Here in the first graph, it has more slopes towards the time axis indicate that the degradation in reliability is more with respect to time. The parallelism of the reliability graph after modification shows that the reliability
degradation rate becomes very slow after the implementation of the concept of redundancy.

After comparing the above two graphs as shown in Fig 8.10, plotted for ROPNR and ROPNR[M] it is found that the reliability degradation rate which was 0.00178 per year previously and decreased to 0.00005 per year when the modification has been done. These figures indicate the better values of enhanced reliability.

(iv) COMPARISON BETWEEN ROCOMPR AND ROCOMPR [M]

![Graph showing reliability enhancement of COMPRESSOR [M] as compared to COMPRESSOR with time](image)

Fig. 8.11: Showing reliability enhancement of COMPRESSOR [M] as compared to COMPRESSOR with time

Though several types of compressors are used in refrigerators here is the main description of the reciprocating compressor only. This reciprocating compressor is called Positive displacement Compressor.

If inside the refrigerator, the problem arises related to the compressor then it is very expensive regarding its repairing and servicing point of view.

If any problem comes in the compressor then buzzing or humming sound starts in the refrigerator and cooling stops.
After observation of data as shown in Fig 8.11, it is also clear that up to the end of the first year the reliability of a compressor remains 99.06% without any modification. It continuously comes down exists only 86.84% at the end of 15th years. So such types of data give a result that frequent problems may occur in the compressor toward the finish of fifteenth years. Therefore it affects the overall performance of a domestic refrigerator.

When modification has been done the reliability degradation rate of the compressor becomes very low. From the Fig 8.11, it is confirmed that the reliability of compressor becomes to 99.66 % at the end of the fifteenth year. This figure of reliability at the end of the fifteenth year confirms that the life and performance both of compressor is increased after modification. This increased figure of reliability for the compressor increases the overall reliability of the compressor or domestic refrigerator.

8.3 CONDENSER
The main reason for choking or blockage in the coil of the condenser is a collection of dirty discharges and fouling in it. So heat transfer capacity of condenser becomes very little. The problem of dirty or blocked condenser in any refrigerator is a general feature.

Choking or blockage in the condenser coil is a common problem and this problem occurs more in the condenser of refrigerators. According to the observation Table 6.1, the complaint regarding choking/blockage of condenser coils was raised in only 1 refrigerator among 216 refrigerators in first time between 4th to 5th years. In this way 3 complaints between 8th to 9th years, 2 complaints between 9th to 10th years, 3 complaints between 10th to 11th years and so on.

In the Fig 8.12, the calculated values of reliability regarding the choking or blockage of the condenser coil for different years are shown. The lifespan of the better performance of refrigerator or its condenser regarding its coil is assumed for 15 years. In the Fig 8.12, two graphs are shown. One of these two graphs has a large inclination.
towards the time axis or horizontal axis and another graph appears as a parallel to the time axis. The actual measurement of the reliability of existing systems for condenser coil regarding its clear functioning is shown in the first type of graph, which appears more inclined towards the time axis. This graph is plotted by the actual analysis of collected data from zero to fifteen years. The other type of graph gives the values of reliabilities for fifteen years after modification or after the implementation of redundancy for connections. Therefore the upper graph among the two gives the actual value of enhanced reliability from starting to next fifteen years.

After observing from the above graphs as shown in Fig 8.12, it can be concluded that the more separation at the endpoints of the graph gives the measure of the actual reliability enhanced figure toward the finish of fifteenth years. The slope of the first graph shows the reliability degradation rate with time. Here in the first graph, it has more slopes towards the time axis indicate that the degradation in reliability is more with respect to time. The parallelism of the reliability graph to the time axis after modification shows that the reliability degradation rate becomes very slow after the implementation of the concept of redundancy.

After comparing the above two graphs as shown in Fig 8.12, plotted for ROCBCC and ROCBCC \([M]\) it is found that the reliability degradation rate which was 0.001093 per year previously and decreased to 0.00002 per year when the modification has been done. These figures indicate the better values of enhanced reliability.

(ii) **COMPARISON BETWEENROLOCC&ROLOCC \([M]\)**
Leakage of the condenser coil is another problem and this problem also occurs more in the condenser of refrigerators. From the observation Table 6.1, it is clear that the complaints regarding leakage of condenser coil come first time only in one refrigerator system among 216 refrigerators between 4th to 5th years. In this way 3 complaints between 8th to 9th year, 2 complaints between 9th to 10th year, 3 complaints between 10th to 11th year and so on.

In the Fig 8.13, the calculated values of reliability regarding the leakage of the condenser coil for different years are shown. The lifespan of the better performance of refrigerator or its condenser regarding its coil is assumed for 15 years. In the Fig 8.13, two graphs are shown. One of these two graphs has a large inclination towards the time axis or horizontal axis and another graph appears as a parallel to the time axis. The actual measurement of the reliability of existing systems for condenser coil regarding its performance is shown in the first type of graph, which appears more inclined towards the time axis. This graph is plotted by the actual analysis of collected data from zero to fifteen years. The other type of graph gives the values of reliabilities for fifteen years after modification or after the implementation of redundancy for connections. Therefore
the upper graph among the two gives the actual value of enhanced reliability from starting to next fifteen years.

After observing from the above graphs as shown in Fig 8.13, it can be concluded that the more separation at the endpoints of the graph gives the measure of the actual reliability enhanced figure toward the finish of fifteenth years. The slope of the first graph shows the reliability degradation rate with time. Here in the first graph, it has more slopes towards the time axis indicate that the degradation in reliability is more with respect to time. The parallelism of the reliability graph to the time axis after modification shows that the reliability degradation rate becomes very slow after the implementation of the concept of redundancy.

After comparing the above two graphs as shown in Fig 8.13, plotted for ROLOCC and ROLOCC [M] it is found that the reliability degradation rate which was 0.001586 per year previously and decreased to 0.000037 per year when the modification has been done. These figures indicate the better values of enhanced reliability.
(iii) COMPARISON BETWEEN ROCOND & ROCOND [M]

![Graph showing reliability enhancement of ROCOND [M] as compared to ROCOND with time]

Fig. 8.14: Showing reliability enhancement of ROCOND [M] as compared to ROCOND with time

The condenser is considered an important component of the refrigeration system. It has its most essential work in a refrigeration system as de-superheating, condensing and subcooling.

It is clear that the reliability of condenser depends on its two things. First is reliability regarding choking or blockage on condenser coil and second is leakage of refrigerant from the coil used to make it. The above said problems are such that it would be difficult to get rid of these fully.

When the overall reliability of the condenser is shown in the graph as shown in Fig 8.14 and it is found that its reliability decreases rapidly in the previous case. And it remained only 96.03 % at the end of 15th year. The figure of reliability is still in its safe zone. But it would surely bring down the reliability of the overall refrigeration system. So its modification is essential. But there is no any other option of modifications except preventive maintenance in the case of the condenser.

When modification has been done the reliability degradation rate of the compressor becomes very low. Form the above graph as shown in Fig 8.14, it is confirmed that the reliability of condenser becomes to 99.91 % at the end of the fifteenth year. This figure
of reliability at the end of the fifteenth year confirms that the life and performance both of condenser is increased after modification. This increased figure of reliability for the condenser increases the overall reliability of a domestic refrigerator.

8.4 FILTER DRIER AND EXPANSION DEVICE (CAPILLARY TUBE)

(i) COMPARISON BETWEEN ROFD & ROFD [M]

![Graph showing reliability enhancement of ROFD [M] as compared to ROFD with time]

Fig 8.15: Showing reliability enhancement of ROFD [M] as compared to ROFD with time

Filter Drier is an important component of any refrigeration system. Filter Drier does two important works in a refrigeration system. First is that it absorbs the water which exists in the shape of contaminants and can generate acid mingling with other elements and secondly it filters dirty and absurd things.

It is clear from Fig 8.15 that the functioning of filter drier that if there comes any problem with it then it gives slowly results but dangerous. It can filter drier to damage and is not in well-working condition then the cooling rate of refrigerator decreases and slowly and slowly it reaches to such a level that total cooling stops in a refrigeration system. It is also dangerous in viewpoint that due to less cooling rates both the
production loss and power loss become simultaneously. It directly affects the profit of consumer. It means an economic loss is there.

Damage of filter drier is another problem and this problem also occurs more in the refrigerators. From the observation Table 7.1 that the complaints regarding the problem in filter drier appear first time only in 2 refrigerators system between 8\textsuperscript{th} to 9\textsuperscript{th} years. In this way 4 complaints between 10\textsuperscript{th} to 11\textsuperscript{th} year, 3 complaints between 11\textsuperscript{th} to 12\textsuperscript{th} year, 4 complaints between 12\textsuperscript{th} to 13\textsuperscript{th} year and so on.

One or two extra Filter Drier should be stored or parallel connected for its modification. By which it should be replaced immediately if chokes. The cost of Filter drier is not so high to be purchased. Its space and weight are also so normal that it can be stored very easily.

Before the application of the concept of redundancy, the reliability which came down to 97.77 % at the end of the 15\textsuperscript{th} year now that reached 99.95 % after application of the concept of redundancy.

(ii) COMPARISON BETWEEN ROLCT AND ROLCT [M]

![Fig 8.16: Showing reliability enhancement of ROLCT [M]as compared to ROLCT with time](image-url)
Leakage of the capillary tube is another problem and this problem also occurs more in the expansion devices of refrigerators. It is clear by the observation Table 7.1 that the complaints regarding leakage of capillary tube come first time only in 2 refrigerators among 216 refrigerators between 6th to 7th years. In this way 3 complaints between 7th to 8th year, 3 complaints between 8th to 9th year, 2 complaints between 9th to 10th year and so on.

In the above graphs as shown in Fig 8.16, the calculated values of reliability regarding the leakage of the capillary tube for different years are shown. The lifespan of the better performance of refrigerator or its expansion devices regarding its capillary tube is assumed for 15 years. In the Fig 8.16, two graphs are shown. One of these two graphs has a large inclination towards the time axis or horizontal axis and another graph appears as a parallel to the time axis. The actual measurement of the reliability of existing systems for capillary tube regarding its performance is shown in the first type of graph, which appears more inclined towards the time axis. This graph is plotted by the actual analysis of collected data from zero to fifteeth years. The other type of graph gives the values of reliabilities for fifteen years after modification or after the implementation of parallel redundancy for connections. Therefore the upper graph among the two gives the actual value of enhanced reliability from starting to next fifteen years.

After observing from the above graphs as shown in the Fig 8.16, it can be concluded that the more separation at the endpoints of the graph gives the measure of the actual reliability enhanced figure toward the finish of fifteeth years. The slope of the first graph shows the reliability degradation rate with time. Here in the first graph, it has more slopes towards the time axis indicate that the degradation in reliability is more with respect to time. The parallelism of the reliability graph to the time axis after modification
shows that the reliability degradation rate becomes very slow after the implementation of the concept of redundancy.

After comparing the above two graphs as shown in the Fig 8.16, plotted for ROLCT and ROLCT [M] it is found that the reliability degradation rate which was 0.001385 per year previously and decreased to 0.000029 per year when the modification has been done. These figures indicate the better values of enhanced reliability

(iii) COMPARISON BETWEEN ROBCT & ROBCT [M]

![Graph showing reliability enhancement of ROBCT [M]as compared to ROBCT with time](image)

Fig. 8.17: Showing reliability enhancement of ROBCT [M] as compared to ROBCT with time

Blockage of the capillary tube is also a common problem and this problem also occurs more in the expansion devices of refrigerators. It is clear by the observation Table 7.1 that the complaints regarding leakage of capillary tube come first time only in two refrigerators among 216 refrigerators between 7th to 8th years. In this way 2 complaints between 8th to 9th year, 1 complaint between 9th to 10th year, 2 complaints between 10th to 11th year and so on.

In the Fig 8.17, the calculated values of reliability regarding the blockage of the capillary tube for 15 years are shown. The lifespan of the better performance of
refrigerator or its expansion devices regarding the smooth functioning of the capillary tube is assumed for 15 years. In the Fig 8.17, two graphs are shown. One of these two graphs has a large inclination towards the time axis or horizontal axis and another graph appears as a parallel to the time axis. The actual measurement of the reliability of existing systems for capillary tube regarding its performance is shown in the first type of graph, which appears more inclined towards the time axis. This graph is plotted by the actual analysis of collected data from zero to fifteen years. The other type of graph gives the values of reliabilities for fifteen years after modification or after the implementation of redundancy for connections. Therefore the upper graph among the two gives the actual value of enhanced reliability from starting to next fifteen years.

After observing from the above graphs as shown in the Fig 8.17, it can be concluded that the more separation at the endpoints of the graph gives the measure of the actual reliability enhanced figure toward the finish of fifteenth years. The slope of the first graph shows the reliability degradation rate with time. Here in the first graph, it has more slopes towards the time axis indicate that the degradation in reliability is more with respect to time. The parallelism of the reliability graph to the time axis after modification shows that the reliability degradation rate becomes very slow after the implementation of the concept of redundancy.

After comparing the above two graphs plotted for ROBCT and ROBCT [M] it is found that the reliability degradation rate which was 0.001091 per year previously and decreased to 0.0000178 per year when the modification has been done. These figures indicate the better values of enhanced reliability.

(iv) COMPARISON BETWEEN ROEXPDEV & ROEXPDEV [M]
Reliability of filter drier and capillary tube has been taken combined because these both are fixed together in a refrigeration system. These are combined in series so final reliability has been taken after using the concept of series combination. After having seen the output graph, it is clear that their combined reliability exists 94.17% during the time span of 15 years. It means that the probability of problems related to filter drier and capillary are very little during its life.

When it is modified then it gives wonderful results. As previously it has been clearly said that in both the cases of filter drier and the capillary tube, the concepts of parallel redundancy are possible and in the modification, it has been done so.

When the overall reliability of expansion devices are observed in the graph as shown in the Fig 8.18, then it is found that its reliability decreases rapidly in the previous case. And it remained only 94.17% at the end of 15th year. The figure of reliability is still in its safe zone. But it would surely bring down the reliability of the overall refrigeration system. So its modification is essential.

When modification has been done the reliability degradation rate of expansion devices becomes very low. Form the Fig 8.18, it is confirmed that the reliability of
expansion devices becomes to 99.88 % at the end of the fifteenth year. This figure of reliability at the end of the fifteenth year confirms that the life and performance both of expansion devices are increased after modification. This increased figure of reliability for expansion devices increases the overall reliability of a domestic refrigerator.

8.5 COST-BENEFIT ANALYSIS

Reliability of the system can be increased using the concept of redundancy. Redundancy involves an increase in the cost of the systems as additional sub-components are used to enhance reliability. In the present study, focus has been increasing in the reliability by employing redundancy only in those sub-components which are more likely fail or malfunction but their price is low and the overall impact on the refrigerator cost is minimal. Apart from low price following factors have been taken into consideration while selecting sub-components for reliability enhancement through redundancy:

1. Components which are not easily available in the market. In case of a sudden failure, the probability of their availability in the market shall be low.
2. The components can be easily stored.
3. The components which can easily be replaced and fitted requiring very less effort and time.
4. The components, which if they connected in parallel redundancy, will occupy less space in the system.

Cost Analysis Selecting a Common Brand:

There are many brands of refrigerators on the market. In the same size and capacity, their prices vary within a price band of 20%. Therefore for cost analysis a typical refrigerator
brand Godrej has been considered in this study. The impact of redundancy on cost is as follows;

The cost of Godrej RD Edge Pro 190 CT 5.2 190 L Single door = Rs. 15290

(Reference: www.indiamart.com)

**New Cost of Modified Domestic Refrigerator after Applying Redundancy:**

(a) The increased cost of evaporator due to following sub-components

Evaporator Tube: 1 piece @ Rs. 400/Piece = Rs. 400

Copper Tube: 3 pieces @ Rs. 10/Piece = Rs. 30

(b) The increased cost of compressor due to following sub-components

Timer: 1 piece @ Rs. 300/Piece = Rs. 300

Suction/Discharge Valve: 1 piece @ Rs. 600/Piece = Rs. 600

Compressor piston ring: 1 piece @ Rs. 40/Piece = Rs. 40

Connecting rod: 1 piece @ Rs. 800/Piece = Rs. 800

(c) The increased cost of condenser due to following sub-components

Condenser coil: 1 piece @ Rs. 400/Piece = Rs. 400

(d) The increased cost of expansion Device (capillary tube) due to following sub-components

Copper Filter Drier: 1 piece @ Rs. 30/Piece = Rs. 30

Capillary Tube: 3 pieces @ Rs. 10/Piece = Rs. 30

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Rate (Rs.)</th>
<th>Total Cost (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaporator Tube</td>
<td>1</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>Copper Tube</td>
<td>3</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Timer</td>
<td>1</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Suction/Discharge Valve</td>
<td>1</td>
<td>600</td>
<td>600</td>
</tr>
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<td>Compressor piston ring</td>
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<td>40</td>
</tr>
<tr>
<td>Connecting rod</td>
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<td>800</td>
<td>800</td>
</tr>
<tr>
<td>Condenser coil</td>
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<td>400</td>
<td>400</td>
</tr>
<tr>
<td>Copper Filter Drier</td>
<td>1</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Capillary Tube</td>
<td>3</td>
<td>10</td>
<td>30</td>
</tr>
</tbody>
</table>

Total Increase in cost = Rs. 2630

% increase in cost = 17.2 %

### 8.6 Cost increase vis-à-vis reliability increase
Application of redundancy increased the cost of the domestic refrigerator by 17.2 % and at the same time the reliability of the system increased from 74.9 % to 99.3 %. Though the increase in cost is there but in certain applications where losses occurring due to a sudden breakdown in the refrigerator are a serious concern this system shall be advantageous. A few examples of cases were sudden failure can lead to huge losses are storage of life-saving and precious medicines, vaccines where maintenance of cold chain is very important and certain expensive chemicals which needs to be stored at a certain temperature. For household application, the increase in cost may not justify the concept of redundancy but a certain elite class of customers may prefer a more reliable system for the sake of convenience. Overall, we may say that the concept of redundancy is beneficial to enhance the reliability of a domestic refrigerator for critical applications[43].