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## RETROFITTING LARGE REFRIGERATION SYSTEMS WITH R-134A

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### ABSTRACT

This paper provides a case history examination of the retrofit of a food processing refrigeration system with R-134a.

In search for alternatives to CFCs, many industry sectors have chosen R-134a as the preferred replacement for R-12. Considerable effort has been made to provide practical solutions to the challenges of new equipment with this new refrigerant, and associated lubricants.

There is a considerable stock of existing equipment for which solutions must also be found, and so there is an increasing attention is being paid to retrofit of existing equipment, with respect to cost and performance. In order to address a solution for continued use of this equipment during its expected lifetime, ICI has addressed the retrofit question with R-134a.

Several retrofits have been conducted throughout the world on large commercial refrigerated food processing and storage facilities. This paper examines one case in detail, and discusses the major issues concerning retrofit. These studies include equipment changes, choice of lubricant, flushing practices, and performance before and after retrofit.

### INTRODUCTION

In the search for alternatives to CFCs, many industry sectors have chosen R-134a as the preferred replacement for R-12. Considerable effort has been made to provide practical solutions to the challenges of new equipment with this new refrigerant and its associated lubricants.

In addition, there is a considerable stock of existing equipment, valued at hundreds of billions of dollars, for which a solution to the question of refrigeration must be found. Increasing attention is being paid to the retrofit of existing equipment, with respect to both cost and performance(1). In an attempt to find a solution for continued use of this equipment through its expected lifetime, we have concentrated efforts in the area of retrofit using R-134a.

R-134a is an attractive alternative to R-12 for many reasons. R-134a has a good performance match to R-12 at medium and high temperature refrigeration conditions, zero ozone depletion potential (ODP) and low direct global warming potential (GWP). In addition, R-134a is also nonflammable, has extremely low toxicity, high thermal stability and is now being commercially produced at several sites around the world.

The nature and extent of the changes that are necessary for conversion to R-134a varies from system to system. In some retrofit field trials, it has been necessary to remove the major system components, namely the compressor, evaporator and condenser, and replace them with new R134a-optimized items. At the other extreme, there have been some systems where only the refrigerant and lubricant have been replaced without the modification or replacement of any equipment components.

However for the large majority of systems, the solution, both in terms of cost and performance, is likely to lie somewhere between these two extremes, with R-134a and a synthetic lubricant replacing the R-12 and mineral oil, and only selected system components being replaced. The number and nature of the changes required is entirely dependent on the individual system's design and therefore it is impossible to make generalizations on the exact changes that will be needed without first evaluating the specific system. Obviously the type and total number of components needing to be replaced will affect the total cost of the conversion. The objective during retrofits has been to minimize the number of parts that needed to be changed whilst maintaining a satisfactory level of system performance. This paper explores

major areas of concern during a conversion, as well as a case study, in hopes of giving some practical insight into the process of retrofitting existing systems.

## OVERVIEW

Before moving on to illustrate KLEA 134a conversion procedures with a case study examples, it would be appropriate to go through some of the key issues surrounding the use of R-134a and synthetic lubricants for retrofit. There are three main areas of interest - system performance, lubricant transfer, and system chemistry.

System performance is becoming ever more crucial as the threat of regulations regarding energy efficiency requirements for refrigeration systems becomes more and more imminent. In addition, some refrigeration systems are designed within close tolerances for capacity. Any loss would be prohibitive, and would require new equipment. As will be shown, with some modifications to the system, a converted R-134a system can yield an equal or better performance than the same system using R-12.

Lubricant transport around the system and especially lubricant return to the compressor, is of critical interest to the system designers. For use in original equipment, it has been shown that the bulk synthetic lubricant behaves in a fashion comparable to that of the mineral oil in the R-12 system in terms of oil circulation rates and oil distribution. However, an additional concern for retrofit purposes is the effect of the residual mineral oil on system behavior. This issue will be addressed later in this paper.

System chemistry is concerned with the chemical reactions that occur in refrigeration systems, including the thermal stability properties of the refrigerant and lubricant, and the compatibility of materials. The materials compatibility area is principally concerned with the behavior of the wide range of nonmetallic components, such as the gaskets, o-rings, motor winding insulation, flexible hoses, paints and coatings that are in contact with the mixtures of refrigerants and lubricants.

## SYSTEM CAPACITY

The equipment modifications that are necessary for any KLEA 134a system to be equal or better than the existing R-12 system with respect to capacity most often consist of: 1.) an upgrade to a new R-134a-optimized expansion device (or an adjustment to the existing device); 2.) the use of an R-134a-compatible desiccant; and 3.) the change of any components necessary as a result of material compatibility issues. It is recommended that the original equipment manufacturer be consulted to supply additional necessary changes which can also effect capacity. (2)

In some systems, particularly those working at the lower end of the evaporating temperature range for R-12, some form of compressor capacity modification may be required in order to maintain system performance; which is primarily due to the specific refrigeration system design which has been optimized for use solely with R-12. For this reason, efforts in the retrofit of R-12 systems have been aimed at the medium to high temperature range where the lack of any requirement to change the compressor displacement greatly simplifies the procedure.

### Capacity versus Evaporator Temperature

The effect of the system isobaric evaporation temperature on refrigeration capacity for a number of isobaric condensation temperatures has been evaluated. As could be expected, both R-12 and R-134a refrigerants behave in a similar fashion with respect to capacity at any given evaporation temperature. The evaporation temperature has been seen to increase as the condensation temperature drops. Related to this, as the difference in condensation and evaporation temperature decreases, the refrigeration capacity increases for both refrigerants. see Figure 1

It may be interesting to note that the curves on the Compressor Capacity curves against evaporating temperature for the two refrigerants actually cross at a point between 32 F and 14 F. Therefore under higher evaporating conditions it is possible to achieve higher capacities with 134a compared to systems running on 12.

### Capacity versus Condenser Temperature

If the same data are considered as a function of condensation temperature for two evaporation temperatures, then, under certain conditions, the capacity of R-134a can be similar or greater than that of R-12. see Figure 2

### Capacity Conclusions

The theoretical calculations for capacity under typical air conditioning and chiller operating conditions show that R-134a is a good match for R-12. These theoretical values have been confirmed by field trials, as well as others, and through several calorimetric studies which have previously been published in the literature. (3)

In addition to capacity, there are other aspects of system performance that should be taken into consideration when evaluating the overall system. For example, the heat dissipation of the condenser unit can also act to limit the retrofit system performance in those cases where the size of the condenser has been optimized for the demands placed upon it by R-12. Although these other areas are outside the scope of this paper, their effects should not be overlooked.

### LUBRICATION AND SYSTEM DURABILITY

The other main performance aspect to be taken into consideration is that of lubrication and its effects on system durability.

Most R-134a basic retrofits will involve changing the lubricants from mineral oil to an appropriate synthetic lubricant. It appears that a small proportion of mineral oil will not have a detrimental effect on system thermal stability, as well as little or no effect on the lubrication performance of ester lubricants.

In the past, some trials were conducted by simply replacing the R-12 with R-134a and reusing the existing mineral oil, with less than satisfactory results. The principal reason for replacing the mineral oil is the oil transport behavior of the R-134a/mineral oil system. R-134a has very low mutual solubility with mineral oil lubricants. This lack of solubility results in a high interfacial tension between R-134a and the oil, and no oil viscosity drop in the presence of the refrigerant. The result is poor mineral oil transport around the system, with the mineral oil 'dropping out' in the evaporator where its viscosity is sufficiently high to resist the draw from the refrigerant vapor flow. In the worst cases, this can lead to oil starvation in the compressor resulting in eventual failure of the system. It would be reasonable to expect that a thick film of viscous, mineral oil lubricant on a heat exchange surface would result in poorer heat transfer. (4)

In oil circulation and distribution studies using mixtures of mineral oils with poly alkylene glycol (PAG) and polyol-ester based lubricants and R-134a, the majority of the mineral oil component can indeed be found in the evaporator, although with esters, around 1-4% of mineral oil can be carried into circulation by the ester. With PAGs, this value is less than 1%. (5,6)

### Why Esters for Retrofit?

Emphasis has been placed on the use of ester lubricants rather than PAGs for retrofit. There are several reasons why, at this stage, esters are the preferred option. Many of these points have been mentioned previously but are worth discussing briefly here.

Polyol ester based lubricants appear to be more tolerant of chlorinated impurities and have better miscibility than many PAGs with mineral oil, both in the presence and absence of refrigerants. There is more work being done in this area in order to clarify the position of retrofit, but at this stage, esters have shown themselves to be the better option.

### SYSTEM CHEMISTRY

The main concern in the area of system chemistry as it impacts on retrofit has been the effects of chlorine-containing residues on the stability and lubrication performance of the R-134a/synthetic lubricant system. There have been a number of reports issued which suggest that R-134a synthetic lubricant systems cannot tolerate the presence of chlorine. This is in fact a gross oversimplification.

Chlorinated residues arise mainly from two sources: residual mineral oil with dissolved R-12 and various decomposition products; and residues from flushing solvents such as R-11 or R-113 that may have been used to remove mineral oil from the system as part of a retrofit.

#### System Chemistry Test Methods

Two test methods have been used to examine the chemical reactions of the refrigerants, lubricants and contaminants in the presence of metals. The first of these, the 'sealed-tube test', is actually conducted in a stainless steel autoclave at elevated temperature.

The other method involves the use of accelerated compressor life tests with the test conditions supplied by the compressor manufacturer. The static sealed-tube test has none of the dynamic features that are present in a compressor system. Therefore, it is valuable to compare the changes in both gas and oil that occur with each different type of test. It is our experience with ester lubricants that the sealed-tube test induces greater levels of chemical change than those found in even the most severe accelerated life test. Table 1 is an example of some actual sealed-tube test results.

#### Sealed-Tube tests R12 Mineral Oil, PAG, Ester

It is apparent that, at least for the ester and PAG shown here, the R-12/synthetic lubricant systems perform as well as, or even slightly better than, the mineral oil under these conditions. It is clear from these results that the presence of chlorine, at least in a sealed-tube test, does not have a catastrophic effect on the synthetic lubricant.

#### Reaction of Contaminated Systems

Table 2 illustrates a limited number of tests based on possible contamination of the R-134a/ester system with mineral oil, R-12, flushing solvents and water. The results, with the exception of the 1% R-11 test, show the superior thermal stability of the R-134a/ester combination. The small level of tarnishing that is observed in those systems containing 1% R-12 and mineral oil is principally a result of the reaction of R-12 on the metal surfaces. These tests also indicate the effect that increased water content has on the system, with approximately 500ppm of water still yielding acceptable performance. As the water level is increased above 500ppm to 2000ppm, performance begins to deteriorate progressively and the hydrolysis of the ester-based stock becomes apparent.

Note that the 1% R11 test was stopped after only seven days due to catastrophic failure of the system.

#### System Chemistry Conclusions

Only a small fraction of the large number of sealed-tube tests that have been conducted are described here. Of the materials presented here, R-11 was the most reactive, with R-12 being the least reactive. This order of instability applies to both PAG and ester lubricants. The reactivity series for chlorinated contaminants has been defined as follows: R11>R113>R12.

The reactivity of the chlorinated contaminant appears to govern the ability of the system to tolerate the contaminant. However, even with a reactive species such as R-11, the effects in sealed-tube tests do vary with the concentration of the contaminant. The topic of acceptable flushing solvents for use in retrofit is beyond the scope of this paper, but for the moment, R-12 is considered to be a valuable option for the majority of systems.

Ester lubricants can in fact be used successfully with R-12 as the refrigerant. The accelerated life tests were conducted using both open and hermetic compressors which had been deliberately doped with varying quantities of R-12. The tests were very successful, with little or no apparent problems. Therefore, esters are a viable option for successful retrofits.

#### Materials Compatibility

Of all of the compatibility issues, the area of nonmetallic or elastomer compatibility is probably the most difficult in terms of providing generic approval for materials in contact with refrigerants and lubricants. The physical properties of many groups of generic elastomers can vary both with the detailed composition of the polymer blend and with the processing history of any particular blend.

Considerable work has been done to evaluate the relative compatibilities of materials with a range of ester lubricants. see Figure 3. The data available to date suggests that a full range of conventional materials will have a satisfactory level of compatibility with R-134a and ester lubricants. (6)

#### RETROFIT

The emphasis in terms of retrofit field trials has been on the air conditioning and chiller areas of the R-12 application spectrum. ICI is active in three main areas:

- i. mobile air conditioning (MAC)
  - automotive
  - trains, buses
  - heavy equipment
- ii. commercial refrigeration
  - cool rooms
  - building air conditioners
  - chillers (e.g. milk chillers)
- iii. plant refrigeration

The section on retrofit procedure has been included to give the reader an idea of the general steps involved in a retrofit. The detailed procedures for a retrofit are system specific and can only result from an in-depth evaluation of the equipment. Therefore, this section is to be used for discussion purposes only and was not intended to act as a step-by-step procedure through the conversion process.

#### Retrofit Procedure

- 1.) Using the compressor, pump the existing refrigerant charge into the receiver, if fitted.
- 2.) Drain the original mineral oil charge from the compressor. If an oil separator is fitted, this should be drained as well.
- 3.) Recharge the system with the new ester lubricant oil.
- 4.) Evacuate the air out of the system and run the refrigeration system using R-12 as the working fluid. The residual mineral oil and the new charge of ester oil should mix totally with the R-12 charge. The system will run successfully with this oil mixture.
- 5.) After running for a period of time sufficient to produce a homogeneous mineral oil/ester mixture, the oil charge is again drained and replaced with fresh ester lubricant. This procedure will help to further reduce the residual mineral oil which remained in the system after the initial draining.
- 6.) The refrigeration equipment is restarted using R-12. The process of draining oil and recharging with a fresh charge is repeated until an acceptably low level of mineral oil in the ester oil is left in the system. The recommended level is less than 1% mineral oil in the ester oil. Systems may be able to operate successfully

with higher residual mineral oils left in the ester oil but at these higher levels the mineral oil may drop out in the evaporator and effect the overall refrigeration capacity of the system. To ensure this does not happen, it is best to reduce the mineral oil down to the recommended level.

7.) At this stage, R-12 is removed and recovered for reuse. The required equipment modifications are now carried out as required, such as replacing expansion valves, driers and any compressor modifications.

8.) After evacuation of residual R-12, the system can be recharged with KLEA 134a. The residual R-12 should not exceed 200 ppm in the KLEA 134a.

#### Case Study - RETROFIT OF KLEA 134a INTO EXISTING INDUSTRIAL R12 SYSTEM

For ICI, a significant part of the development process to introduce KLEA 134a into the refrigeration industry, is to encourage its use in industrial chilling applications. Through considerable support from Cadbury Limited, Bournville and APV Dartford, ICI was recently able to convert an industrial chilling system in the food processing area from R-12 to KLEA 134a.

The machine selected was one of two identical machines with separate primary refrigerant circuits and a common secondary refrigerant circuit, located in a refrigerated chocolate storage area. These two machines provide cooling to two finished product stores with design cooling duties of 60, 614 BTU/Hr and 133, 102 BTU/Hr. The chocolate storage area is where Milk Tray and Roses centers are stored prior to being wrapped.

Chilling of the common secondary glycol system is achieved by two identical and independent refrigeration circuits. Each circuit has an 8 cylinder direct driven compressor with a 15 KW drive motor at 1450 rpm. The glycol, a 30% aqueous solution of inhibited grade monopropylene glycol, is pumped through the evaporators and then to two remote air cooling coils.

The evaporator temperature is designed for 25 F (-3.9 C) and an outlet glycol temperature of 35 F (1.7 C). Glycol temperature control is achieved by loading and unloading the compressor cylinders.

Before the retrofit procedure began, all the basic variables, such as motor power, temperatures, and pressure flow rates, were measured to enable comparisons to be made after the conversion to KLEA 134a.

The first stage of the conversion was to remove the mineral oil used to lubricate CFC-based systems from the compressor crankcase and oil separator. These equipment components were then refilled with ester oil of a viscosity to match ISO VG68 mineral oil saturated with R-12.

After refilling with a synthetic lubricant, the plant was run for four hours. The ester oil, contaminated by mineral oil residues remaining in the system, was then drained. The compressor crankcase and oil separator were refilled once again with the ester oil. This procedure was repeated until the level of the mineral oil within the ester oil was less than 1%. ICI has developed a simple method for testing the oil on-site which can quickly and accurately check the mixture percentage.

A chart of the percentage of mineral oil in each subsequent flush sample is presented in Table 3. It can be seen that a dramatic decrease following the second flush indicates that the majority of the mineral oil was pushed forward out of the system by the ester. In addition, some of the samples appeared cloudy green, not clear yellow as the virgin ester charge. This is most likely associated with the system fluid change from R-12-mineral oil to the more polar combination of KLEA 134a and esters-such as scouring of the system debris is known to occur on introduction of R-22 into existing systems. In order to confirm this hypothesis the samples were filtered with a 1-micron glass filter and the oil analysis reverted back to that of the original base stock, see Table 4. The low acid number and other metal contents indicate little or no oil deterioration.

The R-12 which had previously been used in the system was then pumped out into a recovery cylinder for passing through ICI's recovery and recycling process. At this point, some equipment modification to the plant was required. The expansion valves and filter/drier core needed to be altered to accept the new refrigerant and lubricant package. The system was then tested for leaks.

To enable complete evacuation of the system and to ensure that all traces of R-12 and any contaminants are removed, the triple evacuation method was used. This method requires the system to be repeatedly evacuated to a pressure of 1mm Hg absolute or lower. Once this was completed, the system was charged with KLEA 134a. The gas analysis indicated the successful removal of R-12 from the system using the triple evacuation method.

	Duty KW	Power KW	ODP
R12 predicted (computer model)	29.8	11.3	2.64
R12 measured	27.8	11.1	2.50
KLEA 134a predicted	28.7	10.5	2.73
KLEA 134a measured	28.2	10.1	2.79

KLEA and EMKARATE are trade names, the property of ICI Chemicals & Polymers Limited.

#### CONCLUSION

ICI's work in practically applying the principles and techniques of R-134a retrofit is based on years of intensive research, combining extensive testing at its application facilities in Japan, the UK and the United States, and cooperatively with customers worldwide.

In addition to the highlighted case study discussed here, ICI has also been involved with several retrofits around the world, including applications for cold storage, chillers, heat pumps and automobiles.

More work is being done in order to extend the applicability of the R134a/ester system in several different fronts. From the extensive laboratory work that has been done relative to this area, as well as the number of successfully completed conversions, it can be concluded that R-134a and ester lubricants offer an attractive option for the retrofit of many refrigeration and air conditioning systems currently operating on R-12.

#### ACKNOWLEDGEMENTS

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Figure 1:

**Volumetric Capacity versus  
Evaporator Temperature  
R-12 and R-134a**

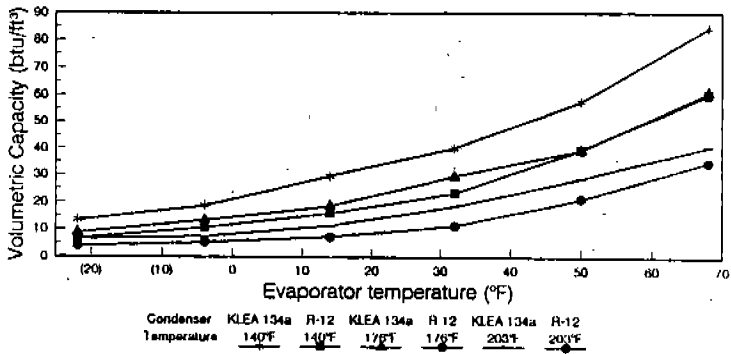


Figure 2:

**Volumetric Capacity versus  
Condenser Temperature  
R-12 and R-134a**

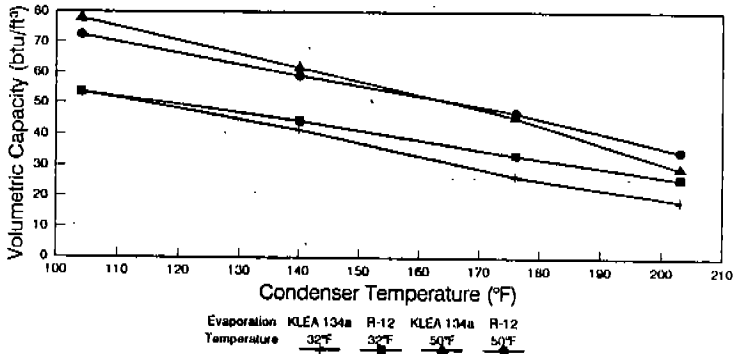


Figure 3:

**Volume Changes of Selected Elastomers  
14 days @ 130°C (266°F) and 600 psig**

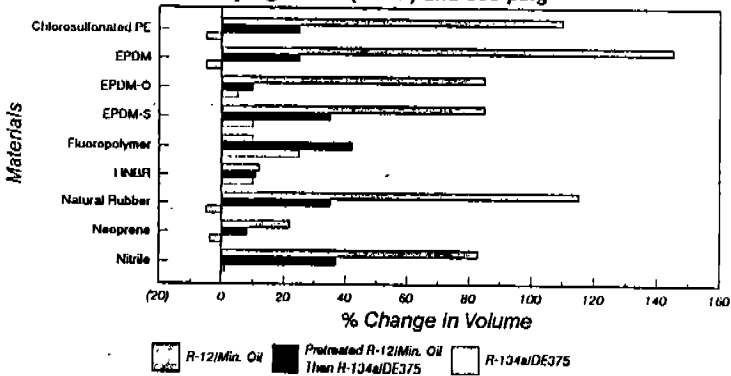


Table 1:

**SYSTEM CHEMISTRY  
SEALED TUBE TEST RESULTS**

	R-12/MO	R-12/PAG	R-12/Ester
Color	Dk Yellow	Yellow	Yellow
Viscosity Change	-5%	-10%	-5%
Final Acid No.	0.4	0.28	0.22
Chloride	87 ppm	23 ppm	23 ppm
Fluoride	below 2 ppm	5 ppm	2 ppm
Metals Appearance	Tarnish, Cu Plating	Tarnish	Tarnish

175 C, 14 days, 1:1 wt/wt oil/Lube

Table 3:

**Retrofit Flush Samples  
Food Processing Plant**

	Fresh Oil Analysis	1st Flush Mixture	2nd Flush Mixture	3rd Flush Mixture	4th Flush Mixture
APPEARANCE	Pale Yellow	Brown	Dark Green	Light Green	Pale Green
ACID NO (mg KOH/g)		0.05	0.08	0.05	0.03
% Mineral Oil		80	8	0.5	0
Water (ppm)	<10, F<1	<18, F<1	<12, F<1	<18, F<1	<17, F<1
Metals (ppm)					
Al	1	2	35	1	1
Cu	1	22	8	1	1
Fe	1	10	18	6	4
Zn	2	1.5	less than 1	less than 1	less than 1
Pb	n/a	less than 5	less than 5	less than 5	less than 5
Sn	n/a	8	7	less than 5	less than 5

Table 2:

**SYSTEM CHEMISTRY  
SEALED TUBE TEST RESULTS**

Appendix Page 2

	R134a + 1% R12 Ester	R134a + 1% R12 water < 30 ppm 80% Ester/20% MO	R134a + 1% R12 water 500 ppm 80% Ester/20% MO	R134a + 1% R11 Ester
Color	Pale Yellow	Yellow	Yellow	Black
Initial TAN	below 0.05	below 0.05	below 0.05	below 0.05
Final TAN	0.08	0.08	0.05	5.5
Al/Cu/Fe Corros	below 1 ppm	below 1 ppm	below 1 ppm	n/a
Cu Appearance	No Effect	Sl Tarnish	Tarnish	Corroded
Fe Appearance	No Effect	Sl Tarnish	Sl Tarnish	Corroded
Al Appearance	No Effect	No Effect	No Effect	Fibed

175 C, 14 days, 1:1 wt/wt oil/Lube

Table 4:

**Retrofit Oil Analysis  
Food Processing Plant**

	24 Hours After Final Ester Charge	Fibred 24 Hour Sample	One Week After Final Ester Charge	Fibred One Week Sample
APPEARANCE	Cloudy, Green	Pale Yellow	Cloudy, Pale Green	Pale Yellow
ACID NO (mg KOH/g)	0.03	0.03	0.03	0.03
Water (ppm)	<12, F<1	<18, F<1	<18, F<1	<17, F<1
Metals (ppm)				
Al	2	below 1	1	1.4
Cu	3	0.5	2	0.5
Fe	15	7	8	8
Zn	4	below 1	4	4
Pb	below 5	n/a	below 5	n/a
Sn	n/a	n/a	n/a	n/a