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New Methods of Determining Viscosity and Pressure of Refrigerant/Lubricant

H. O. Spauschus
Spauschus Associates

D. R. Henderson
Spauschus Associates

SELECTION AND PERFORMANCE OF SYNTHETIC AND SEMI-SYNTHETIC LUBRICANTS FOR USE WITH ALTERNATIVE REFRIGERANTS IN REFRIGERATION APPLICATIONS

Glenn D. Short
CPI Engineering Services, Inc.
P.O. Box 1924
Midland, Michigan, USA

Richard Cavestri
Imagination Resources
3001 Bethel Rd. Suite 100
Columbus, Ohio, USA

ABSTRACT

The recent interest in developing replacement refrigerants for CFC-12 has resulted in renewed interest in synthetic and semi-synthetic lubricants. Historically synthetic lubricants have been used to increase efficiency and improve reliability in refrigeration systems. Many of the new alternative refrigerants and refrigerant blends require the use of synthetic lubricants. They are needed to obtain solubility for adequate lubricant supply to compressor bearings and return from the refrigerant system. This paper discusses recent developments in refrigeration lubricant technology. Advantages of various synthetic and semi-synthetic lubricants with R-717, Hydrocarbons, HCFC-22, HFC-134a and other alternatives to CFC-12 are described.

INTRODUCTION

The lubricant in a refrigeration system compressor has direct interaction with the refrigerant within the compressor and in other parts of the system. Lubricant performance is becoming more demanding due to the high level of development activity with alternative refrigerants. Complex esters offer particular advantages in HCFC-22 applications. Performance properties of synthetic lubricants for HFC-134a and HFC-152a are investigated and found, to be a necessary alternative to mineral oils. Polyalphaolefin type synthetic hydrocarbons and semi-synthetic hydrotreated oils provide superior operating efficiency in ammonia systems. The use of polyalkylene glycols has become common practice with hydrocarbon refrigerants.

Solubility (vapor-liquid equilibrium) and miscibility (liquid-liquid equilibrium) relationships between refrigerant and lubricating fluids are important design considerations for compressor operation and system design. Methods for accurately predicting these relationships with halocarbon refrigerants are not exact for mineral oils and will require more investigation for synthetic lubricants. /1/2/ Miscibility characteristics of selected synthetic lubricants and alternative refrigerants are presented.

LUBRICANTS FOR REFRIGERANT-134a (HFC-134a) APPLICATIONS

HFC-134a (CH_2FCF_3) is one alternative for CFC-12. HFC-134a is highly insoluble and non-miscible with conventional mineral oils, alkyl benzenes, polyalphaolefins (PAOs) and most other common refrigeration lubricants.

Miscible types of polyalklene glycols (PAGs) were tested in refrigerators using small reciprocating compressors with HFC-134a. /3/4/ Lower viscosity PAGs often have good miscibility with HFC-134a. The higher viscosity grades, above ISO 100, provide an efficient operating viscosity in the presence of the refrigerant for sealing during compression and bearing lubrication. This is desirable for rotary compressors and certain air cooled reciprocating compressor applications (i.e. automotive). The miscibility of various polyglycols with HFC-134a appear in figures 1 & 2.

Increasing the viscosity of polyglycols reduces miscibility, especially at higher temperatures. End groups (hydroxyl) and internal structure (propylene or ethylene) at the lubricant molecule also have an influence as seen in figure 3.

Miscible fluorinated and polyglycol oils with HFC-134a may suffer some lubricity problems possibly due to a lack of adequate lubricant film. The absence of chlorine may make the refrigerant itself less of a lubricant with the oil.

Certain types of low viscosity neopentyl esters have good miscibility with HFC-134a./4/ Random areas of high temperature immiscibility were described as a potential problem. The authors have identified completely miscible types of esters.

Hermetic compressor manufacturers are concerned with the compatibility of these types of synthetics with motor insulation materials. Compatibility with insulation components such as mylar or wire enamels, is an issue with the polyglycols. Other problems with the polyglycols may be their tendency to absorb water and degradation of the lubricant either through use or storage. Copper transfer (copper plating) has been observed in some instances. At least one preliminary study suggested little problem with polyglycols or esters./4/

Several experimental synthetic lubricants have some miscibility with HFC-134a. EXP-139 is a 100 ISO grade oil that is soluble with mineral oil and partially miscible with HFC-134a, Figure 4. Lower viscosity variations of this experimental lubricant are completely miscible with R-134a. The compatibility with materials and lubricity of these lubricants may be different from PAGs.

A polyglycol, EXP-0272, has successfully lubricated a twin screw rotary compressor./5/6/7/ Volumetric efficiency (+2%), refrigeration capacity (+21%) and coefficient of performance (+12%) were all several percent higher than with CFC-12 for constant pressure ratio comparison. CFC-12 data was obtained using an equivalent viscosity (at compressor discharge temperature) polyalphaolefin (PAO) as the lubricant. PAOs show better compressor performance with CFC-12 than equivalent viscosity naphthenic oils in similar tests. This polyglycol, Figure 5, has excellent miscibility with R-134a at condenser and evaporator conditions but becomes less soluble within the compressor rotor bores /7/. A high viscosity during the compression cycle results in more efficient sealing between the rotors and between rotor and compression cylinder walls.

HFC-152a APPLICATIONS

Although combustible, HFC-152a is a possible alternative for CFC refrigerants. Experimental esters have good miscibility with HFC-152a as in Figure 6.

HCFC-22 AS AN ALTERNATIVE

The lower ozone depletion potential of HCFC-22 has made this refrigerant part of the short term solution to the ozone problem. Large rotary screw compressors may be used to replace centrifugal compressors in water chilling applications. Rotary screw compressors are also becoming more important in brine chilling applications, industrial, and transportation applications. Synthetic lubricants are providing efficiency and operational improvements.

Higher viscosity complex esters present a new class of refrigeration lubricants./5/ All viscosity grades of the complex ester oils tested are completely miscible with HCFC-22 to -90°F (-68°C). A high viscosity index and good low temperature fluidity adds to these properties for excellent low temperature behavior. High viscosity grades, 100 to 320 ISO, with high viscosity indexes provide efficient compression sealing in rotary compressors. Figure 7 provides an estimate of the viscosity/temperature characteristics of this oil with HCFC-22. Systems with oil/gas separators have the additional benefit of a very low vapor pressure. Swelling of elastomers is less than with conventional neopentylesters.

Rotary Screw compressor bench tests have shown performance improvements up to a pressure ratio of 4./8/ Field testing has shown that better efficiency improvements in heat exchangers through high miscibility with the refrigerant and better heat transfer properties of the lubricant itself.

AMMONIA (R-717) AS AN ALTERNATIVE

Ammonia (NH_3) has no effect on the ozone layer. Favorable behavior of R-717 (as an alternative refrigerant) with mineral oil has been described as low foaming, low solubility and low miscibility./9/ Oil is easily drained from evaporators on a periodic basis. R-717 has potential new applications as an alternative. Applications include large capacity water chillers, domestic refrigerators and freezers, automotive air conditioners, as a replacement for HCFC-22 in air conditioning and in industrial refrigeration and antifreeze chillers.

Ammonia has a high ratio of specific heats (C_p/C_v) and thus has a high adiabatic compression temperature./10/ In reciprocating compressors, conventional oils can easily carbonize or produce varnish. The oil in rotary screw compressors constantly circulates to remove heat of compression, seal rotors and provide lubrication to rotors, bearings and shaft seals. This constant recirculation requires a chemically and thermally stable lubricant. Reactions with ammonia, water and oxygen can produce nitrogen compounds and acids. These contaminants deteriorate the oil and carry over into the system forming sludge and deposits./11/12/

"Semi-synthetic" high viscosity index (HVI) hydrotreated oils and polyalphaolefins for R-717 applications have been described for ammonia applications./5/12/13/ The hydrotreating (or more accurately "hydrocracking") process uses two high pressure (3000 psi, 20,685 KPa) hydrogen steps at high temperature (700°F, 371°C) over an active catalyst.

HVI hydrocracked lubricants provide several advantages in ammonia systems. Major properties are:

- Superior oxidative, thermal and chemical stability
  - Long life
  - Cleaner operation
- Lower mutual solubility with ammonia
- Low foaming tendency
- Low volatility
  - 30 to 90% less oil consumption
- Excellent low temperature fluidity
- High viscosity index
- Good demulsibility (separation from water)
- Non-toxic

The lower miscibility of the HVI hydrocracked oil, Figure 8, is due to its lower content of aromatic or polar contaminants. Lower solubility with ammonia results in improved bearing lubrication, increased compression efficiency and less foaming.

The properties described would suggest energy savings may result by using HVI hydrotreated oil. Rotary screw compressors have improved volumetric efficiency. This results from a higher operating viscosity and less refrigerant dissolved in the lubricant./14/ Cleaner operation in these compressors will result in less separator blockage. A pressure drop of 10 PSI across a separator can result in a three to five percent loss of energy efficiency in rotary screw compressors. Less carbon build up on discharge valves in reciprocating compressors limits a loss of efficiency due to recompression. A more stable lubricant limits loss of efficiency through viscosity increase. Heat transfer efficiency improvements of ten percent or more may be achieved through lower oil carryover into evaporators./15/

BUTANE (HC-600) PROPANE (HC-290) AND OTHER HYDROCARBON REFRIGERANTS

Butane, propane and other flammable hydrocarbons are possible substitutes for CFC-12 in refrigeration or automotive applications. Blends are also considered to provide comparable evaporation pressure and refrigeration capacity. ISO butane (HC-600a) and cyclo propane (HC-270) may be considered alone or in combination with other hydrocarbon refrigerants.

Hydrocarbon refrigerants, are highly soluble in mineral oils. Viscosity loss due to dissolved hydrocarbon gas in the compressor oil results in a lower viscosity and reduced oil film thickness. The washing away or absorption of lubricant into the gas phase in the compression cylinder may result in loss of lubrication. These problems have led to the widespread use of polyglycols. Polyglycols have lower solubility with hydrocarbons. The polar nature of these fluids helps wet lubricated surfaces. Their high viscosity indexes and the availability of high viscosity grades provide a higher viscosity for sealing during compression, while maintaining a lower viscosity needed for good oil return from the low temperature side of the refrigeration system. Reports by rotary screw compressor developers show up to an eighteen percent improvement in volumetric efficiency over mineral oil in propane compression. High pressure reciprocating compressors have up to a twenty-fold increase in the life of pressure packing while cylinder oil feed rates are reduced.

The miscibility characteristics of hydrocarbons in these lubricants are shown in figures 9 and 10. The less miscible polyglycols also have less solubility for improved compression efficiency. The polyglycol has a higher specific gravity and is easily recovered from the lower area of evaporators. Polyglycols can be designed for an optimum combination of compressor efficiency and system performance.

CONCLUSION

A review of synthetic fluids for compressor lubrication has been made with specific application to refrigeration compressor and system performance. These lubricants offer improved system performance over mineral oils. Their unique miscibility characteristics make them the only choice for R-134a and other HFC type refrigerants. Synthetic lubricants are available to provide improved compressor efficiency in HFC-134a, HCFC-22, and hydrocarbon refrigerants. Hydrotreated (or hydrocracked) semisynthetic oils lower oil consumption, provide greater cleanliness and offer efficiency advantages in R-717 applications.

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MISCIBILITY OF POLYGLYCOLS WITH HFC-134a
MONOFUNCTIONAL POLYPROPYLENE GLYCOL

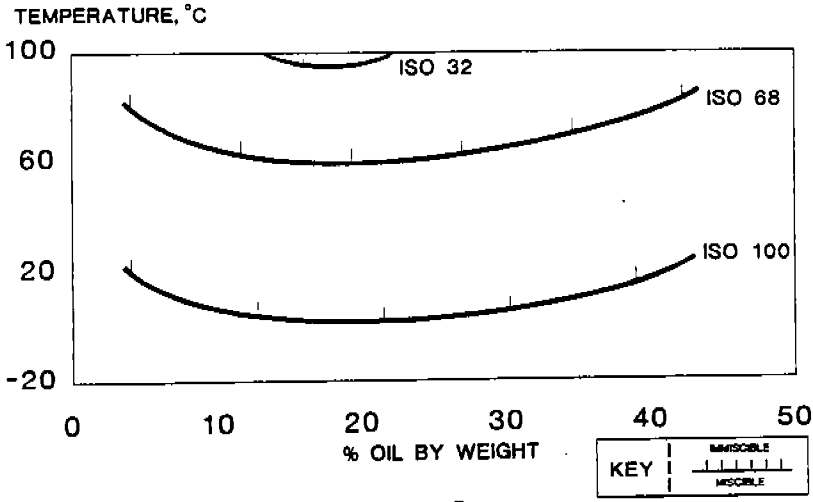

FIGURE 1

MISCIBILITY OF POLYGLYCOLS WITH HFC-134a
DIFUNCTIONAL POLYPROPYLENE GLYCOL

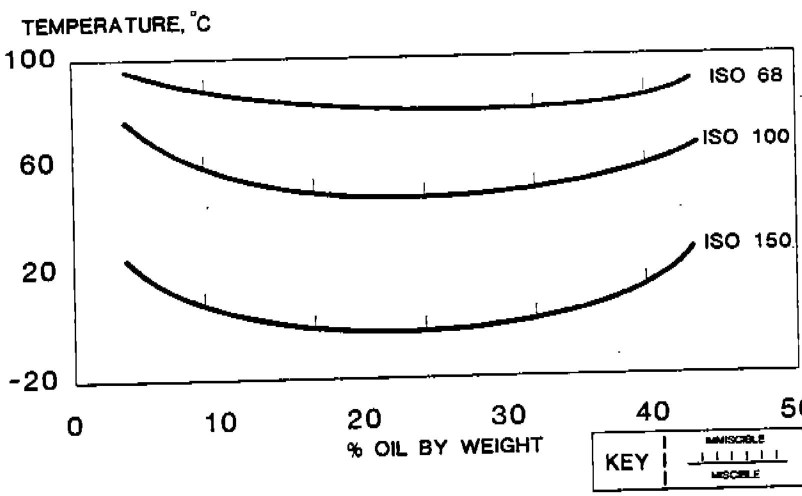

FIGURE 2

MISCIBILITY OF POLYGLYCOLS WITH HFC-134a
VARIOUS FUNCTIONAL GROUPS, ISO 100

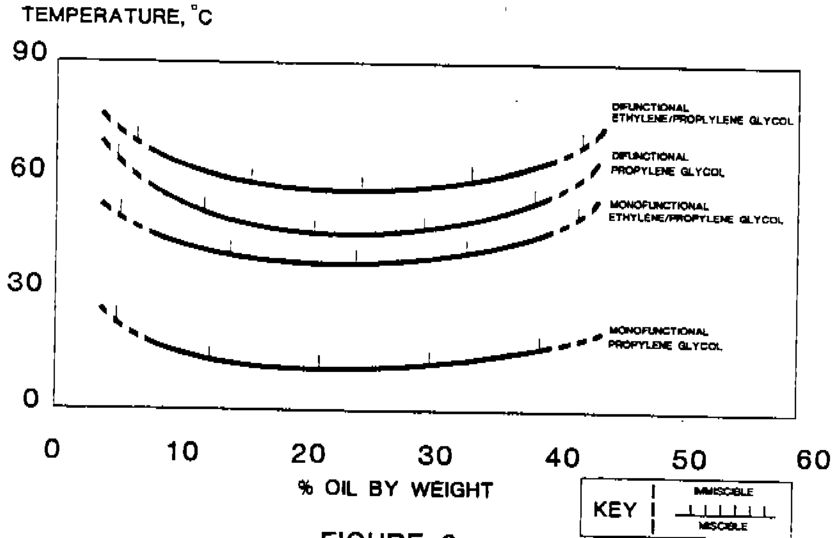

FIGURE 3

MISCIBILITY OF EXP-0139
HFC-134a

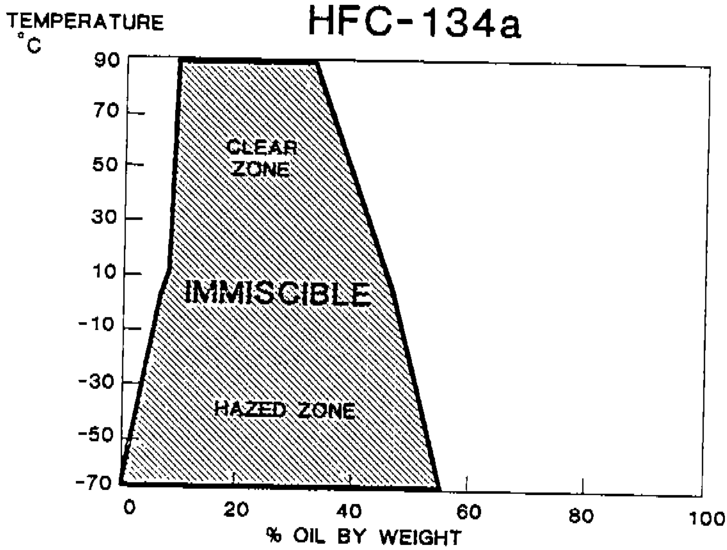

FIGURE 4

MISCIBILITY LIMITS W/ HFC-134a

EXP-0272

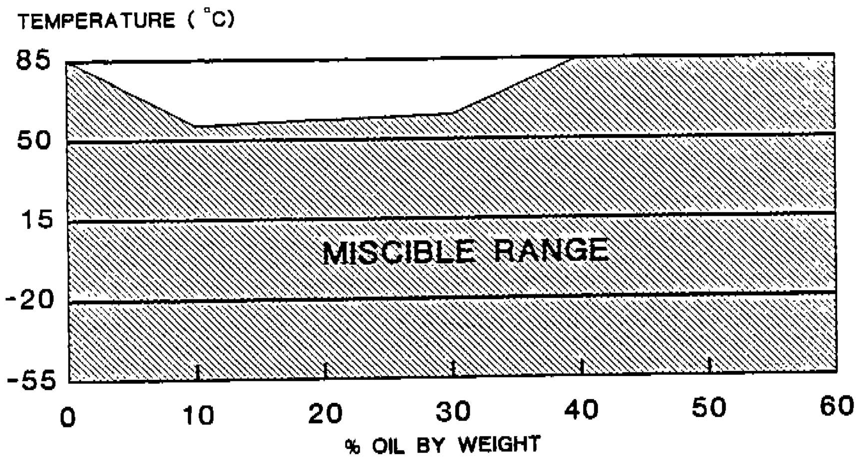

FIGURE 5

MISCIBILITY LIMITS W/ HFC-152a

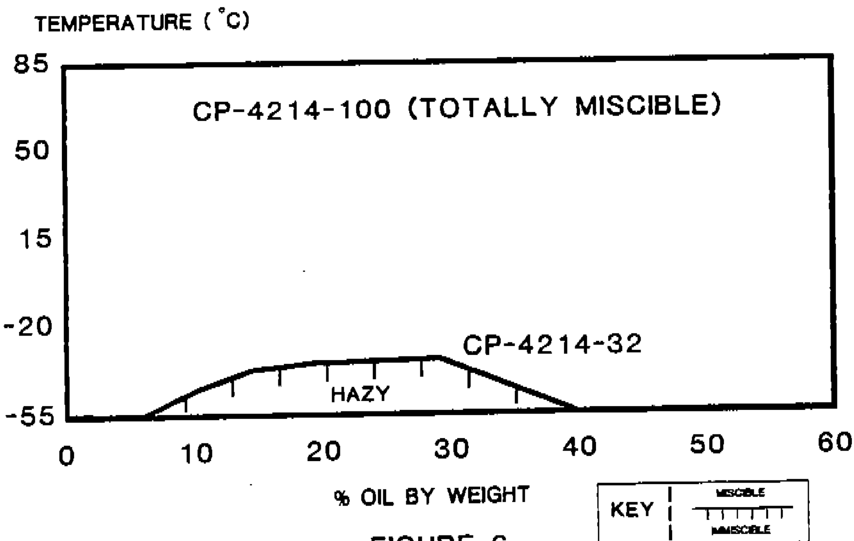

FIGURE 6

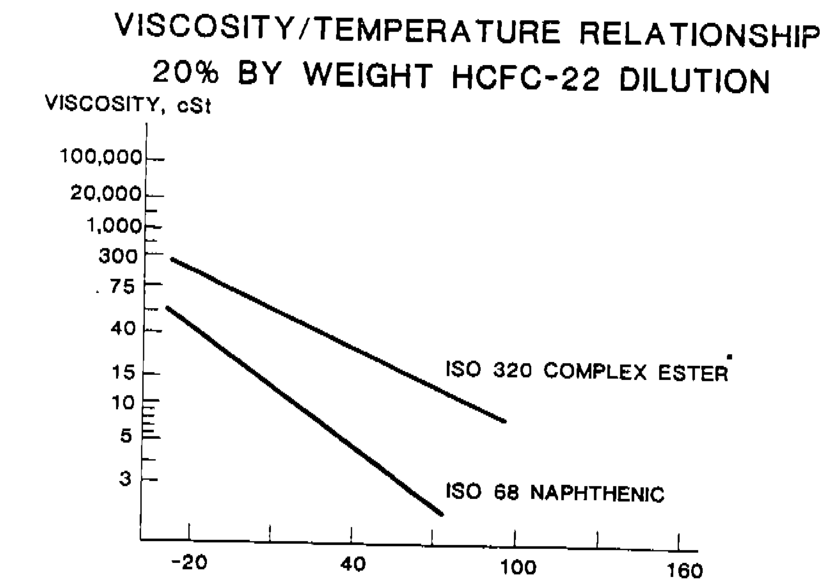

FIGURE 7

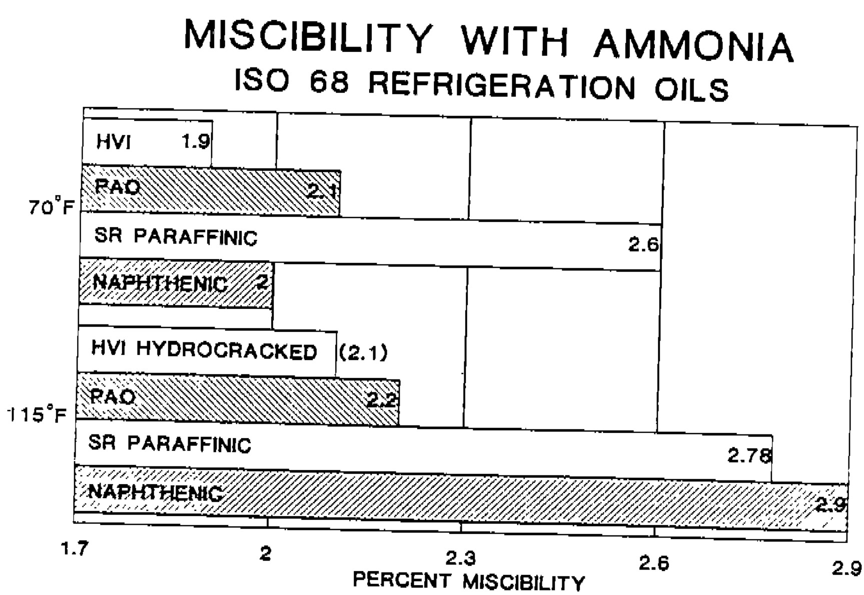

FIGURE 8

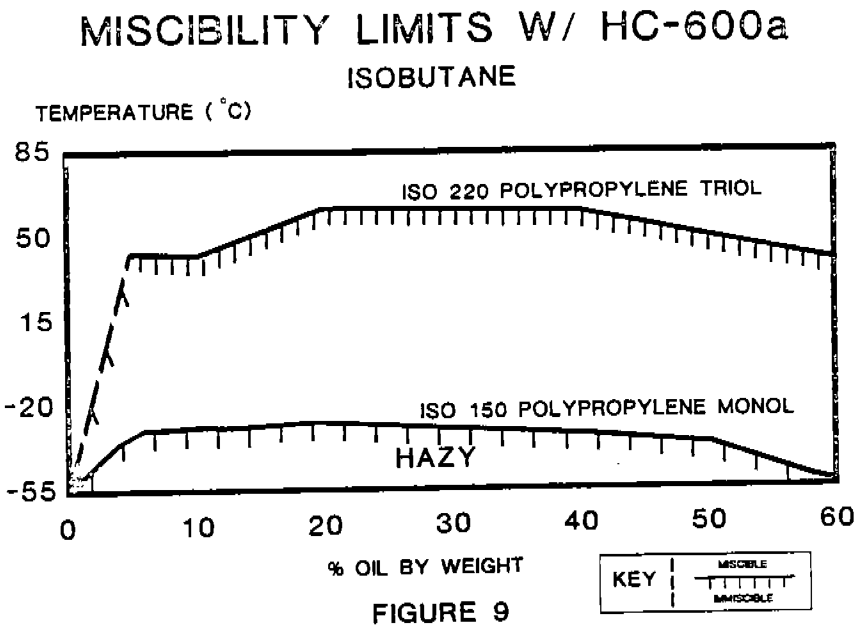

FIGURE 9

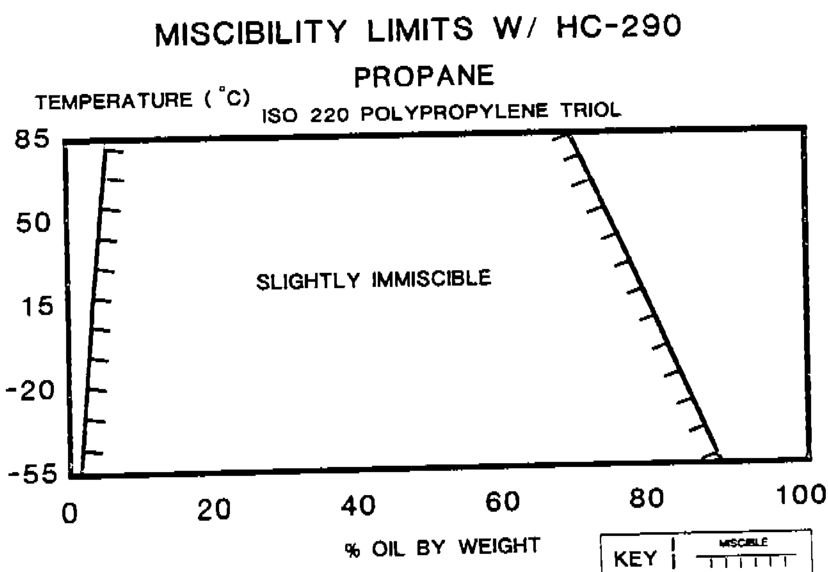

FIGURE 10