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# Oil Meets Cool: Inside the World of Lubricant-Refrigerant Properties

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***The interaction between lubricants/oils and refrigerants plays a pivotal role in the performance and reliability of HVAC and refrigeration systems, yet it is often overlooked in system design. This article explores the dual impact of oil and natural refrigerants mixtures on thermophysical properties and heat transfer. It highlights how dissolved refrigerants affect lubricant behavior in the compressor, and conversely, how oil presence in the circulating refrigerant influences system efficiency. Through analysis of miscibility curves and thermodynamic behavior, particularly with propane (R290) and various synthetic oils, the article emphasizes the importance of selecting appropriate refrigerant-oil combinations. A comprehensive understanding of these interactions is essential for optimizing system performance and ensuring stable lubrication.***

## Introduction

In refrigeration and HVAC systems, the interaction between lubricants/oils and refrigerants is often overlooked during design simulations, which adversely affects the performance of the system. The amount of oil that dissolves into the circulating refrigerant can directly affect the system's Coefficient of Performance (COP) and alter the refrigerant's thermophysical properties. Conversely, the amount of refrigerant that mixes with compressor lubricant in the crankcase can have a major impact on key oil properties like viscosity, miscibility, and thermal stability. Figure 1 shows clearly that low viscosity values lead to poor lubrication (film thickness) and low volumetric efficiency, whereas high viscosity values lead to good lubrication but high frictional losses or low mechanical efficiency.

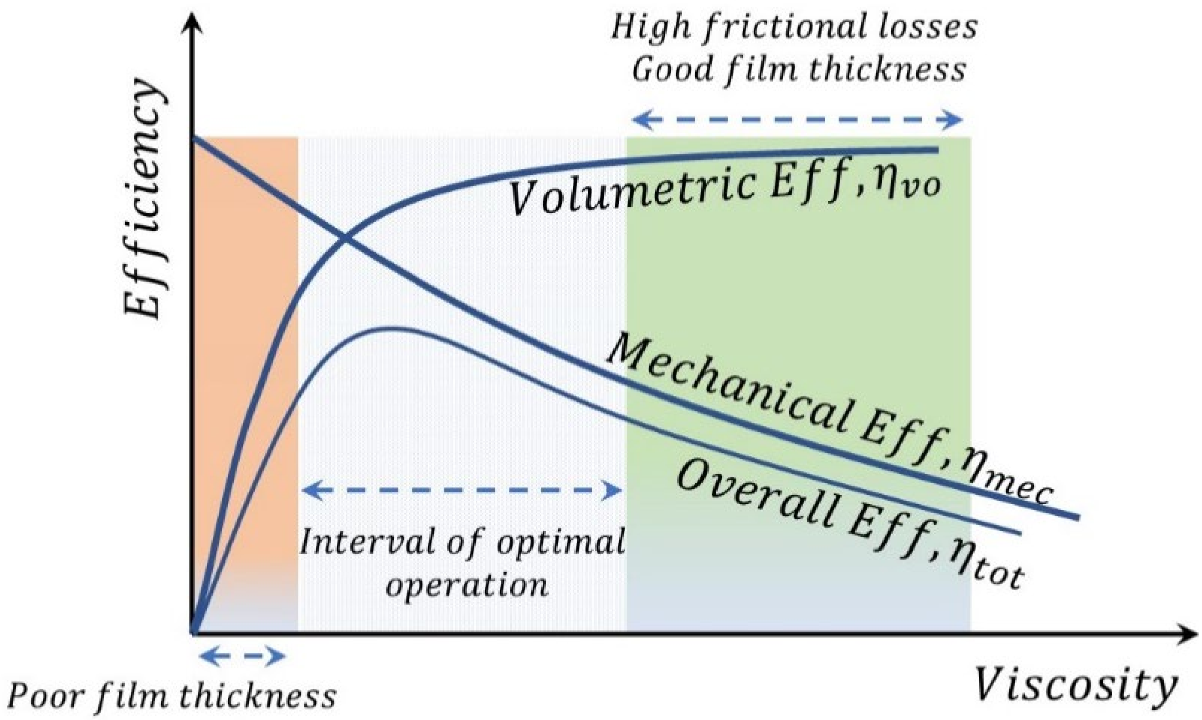


***Figure 1: The effect of viscosity on compressor's efficiency***

Lubricants/oils frequently used for synthetic or natural refrigerants are mineral oils (MOs), alkylbenzenes (ABs), Poly-alpha-olefins (PAOs), poly-alkylene-glycols (PAGs), polyvinyl-ethers (PVEs), and poly-ol-esters (POEs). Rudnick's book "Synthetics, Mineral Oils, and Bio-Based Lubricants, Chemistry and Technology," puts together an excellent introduction to all types of synthetic lubricants.

The relationship between lubricants and refrigerants should be clearly defined by distinguishing between the Lubricant-Refrigerant Mixture (LRM), which focuses on the effect of refrigerants on lubricants within the compressor sump, and the Refrigerant-Oil Mixture (ROM), which examines how dissolved oil in the circulating refrigerant influences the refrigeration system and alters the refrigerant's thermophysical properties. Figure 2 highlights key factors that must be addressed, including miscibility and thermal behavior, which are critical in the evaporator, variations in oil content can shift the refrigerant's boiling point, and oil retention in the evaporator and condenser can reduce heat transfer efficiency, ultimately lowering the system's cooling capacity and coefficient of performance.

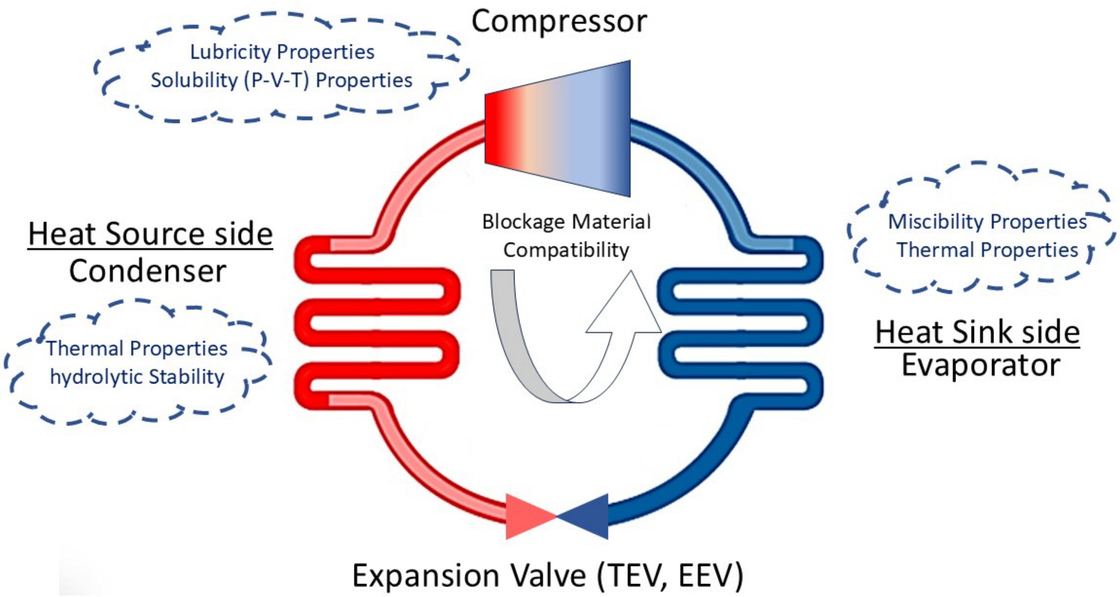


***Figure 2: Oil-refrigerant issues in heat pump components***

**Lubricant-Refrigerant Mixture (LRM) Properties**

The effect of the vapor or liquid refrigerant within the lubrication fluid in the compressor sump changes the properties of the lubricants. These properties are dynamic viscosity, solubility, kinematic viscosity, viscosity index (VI), lubricity, pour point, thermal and hydrolytic properties, and oxidation stabilities. Only dynamic viscosity will be further explored in this article.

Dynamic viscosity ( $\mu_{RLM}$) selection depends upon minimum film thickness required to avoid wear surfaces, maximum allowable viscous drag, minimum sealing, minimum flow rate, and minimum variation within the operating envelope [1]. The viscosity of the lubricant in the presence of any refrigerant may decrease as much as an order of magnitude, since the refrigerant viscosity is typically 2 to 3 orders of magnitude smaller than that of oil [2]. LRM viscosity can also be obtained from specific *PVxT* charts. The parameters used to construct these charts are pressure, temperature, solubility, and kinematic viscosity. The combined *PVxT* data that includes isobaric curves is called the Daniel Plot [3].

The plot of any mixture is derived from refrigerant solubility data ($x$), density data ($\rho$), and viscosity data versus temperatures. To get the dynamic viscosity of a specific LRM:

1. Pressure and temperature are selected first.
2. Pressure versus temperature is used to measure solubility parameters.
3. Solubility versus temperature is used to measure kinematic viscosity (KV or $\vartheta = \mu/\rho$, cSt) and density parameters.
4. Dynamic viscosity ($\mu$, cP) is obtained by the product of KV and density.

Other ways to obtain kinematic viscosity ( $\vartheta_{RLM}$) can be given analytically by relating the viscosity of the lubricant and the refrigerant as in equation (1) [4].
where $(\gamma_{ref})$ is the refrigerant mass fraction.

$$ln\, \vartheta_{RLM} = (1 - \gamma_{ref}) * ln\, \vartheta_{lubricant} + \gamma_{ref} * ln\, \vartheta_{ref}$$

**Eq. (1)**

**Refrigerant-Oil Mixture (ROM) Properties**

The ROM properties do not differ from LRM properties, but miscibility-solubility properties and the thermo-physical properties are the most critical issues that need to be evaluated to understand the effect of the mixture on the energy efficiency of the systems and their performance.

**Miscibility - Solubility**

Miscibility is the property of two substances that completely mix in all proportions or concentrations to form a homogeneous, clear solution, where solubility is the ability of one component (the solute) to dissolve in the other component (the solvent) till saturation point or phase separation occurs. An example of miscible solutions is water and alcohol. The chemical miscibility of the refrigerant-oil mixture is a good indicator of how well the refrigerant will help move the oil around the system. We must indicate that the amount of oil circulated with the refrigerant is small, but its effect is crucial. The miscibility property is crucial to prevent phase separation between the oil and refrigerant mixture, especially in the evaporator.

Miscibility is typically studied by mixing known concentrations of refrigerant and oil and lowering the temperature until a phase separation is observed [5]. The results are used to plot a curve of concentration versus temperature, which indicates the miscibility boundaries before causing separation of an oil-rich phase. The curve shows the amount of refrigerant mixed with the oil-rich phase (solubility of refrigerant in oil). Knowing where the separation phase will form and how much refrigerant is needed to dilute an oil-rich phase can help determine which types of oils are acceptable for use with a given refrigerant [6].

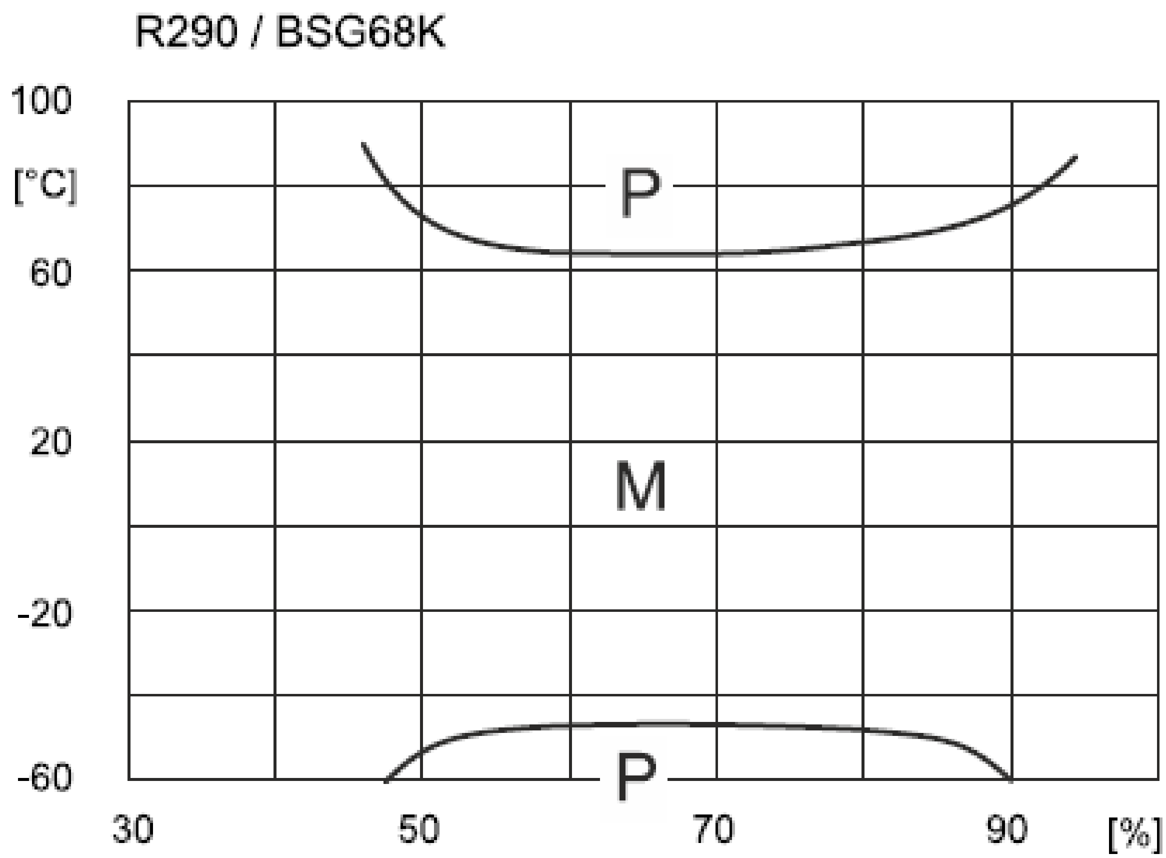


***Figure 3: Miscibility gaps for R290 (Image courtesy of Bitzer Compressors)***

Figure 3 shows the miscibility curves of PAG oils (BSG58K) with refrigerant R290; the figure has been taken from Bitzer compressors [7], where the horizontal axis represents the oil mass concentration. The target zone of full miscibility (M) spans from -40℃ to 60℃ across all oil concentrations, while the phase separation regions (P) are located at the top and bottom of the figure.

According to Bitzer, PAO oils like SHC226E offer excellent miscibility with refrigerants, remaining fully miscible from -60°C to 100°C across all oil concentrations. This prevents phase separation, ensuring stable lubrication, efficient oil return, and consistent thermophysical properties, key for reliable performance in refrigeration and heat pump systems. The broad miscibility range also simplifies system design and enhances flexibility, making SHC226E ideal for applications with wide temperature variations.

**Thermo-Physical Properties**

The refrigerant-oil mixture can lead to reduced heat transfer coefficients, decreased cooling or heating capacity, and a lower COP for the heat pump system. Understanding these thermophysical property changes is essential for accurate modeling, simulation, and design optimization of heat pump cycles.

When the working fluid in a heat pump or refrigeration system shifts from a pure refrigerant, whose thermophysical properties are well-established and well-understood, to a mixture of refrigerant and lubricating oil, the behavior of the fluid becomes more complex and less predictable. This transformation introduces new challenges in system analysis and design, as the properties of the refrigerant-oil mixture are strongly dependent on both the type of oil used and its concentration within the cycle.

One of the key impacts of this change is on the heat transfer processes occurring in critical components such as the evaporator and condenser. The presence of oil alters fluid properties such as viscosity, thermal conductivity, specific heat, and boiling characteristics, all of which directly influence heat transfer efficiency. In some cases, the oil can enhance heat transfer by improving film stability or modifying surface tension, but more often it impairs performance by increasing thermal resistance and reducing the effective heat transfer coefficient. The overall effect, whether beneficial or detrimental, depends largely on the oil concentration, operating conditions, and the nature of the refrigerant – oil interaction. According to Raoult's Law, the introduction of oil into the refrigerant increases the boiling point of the mixture compared to that of the pure refrigerant. This elevation occurs because the oil effectively lowers the vapor pressure of the refrigerant, requiring a higher temperature to achieve phase change. This shift can disrupt the thermal balance within the evaporator and impact system control strategies based on pressure–temperature relationships.

Moreover, during the evaporation process, the oil holds a portion of the refrigerant dissolved or trapped within the liquid phase. As a result, less refrigerant is available to undergo phase change, leading to a reduction in latent heat absorption. This directly decreases the heat-carrying capacity of the working fluid, which in turn lowers the cooling or heating output of the system and can negatively affect COP.

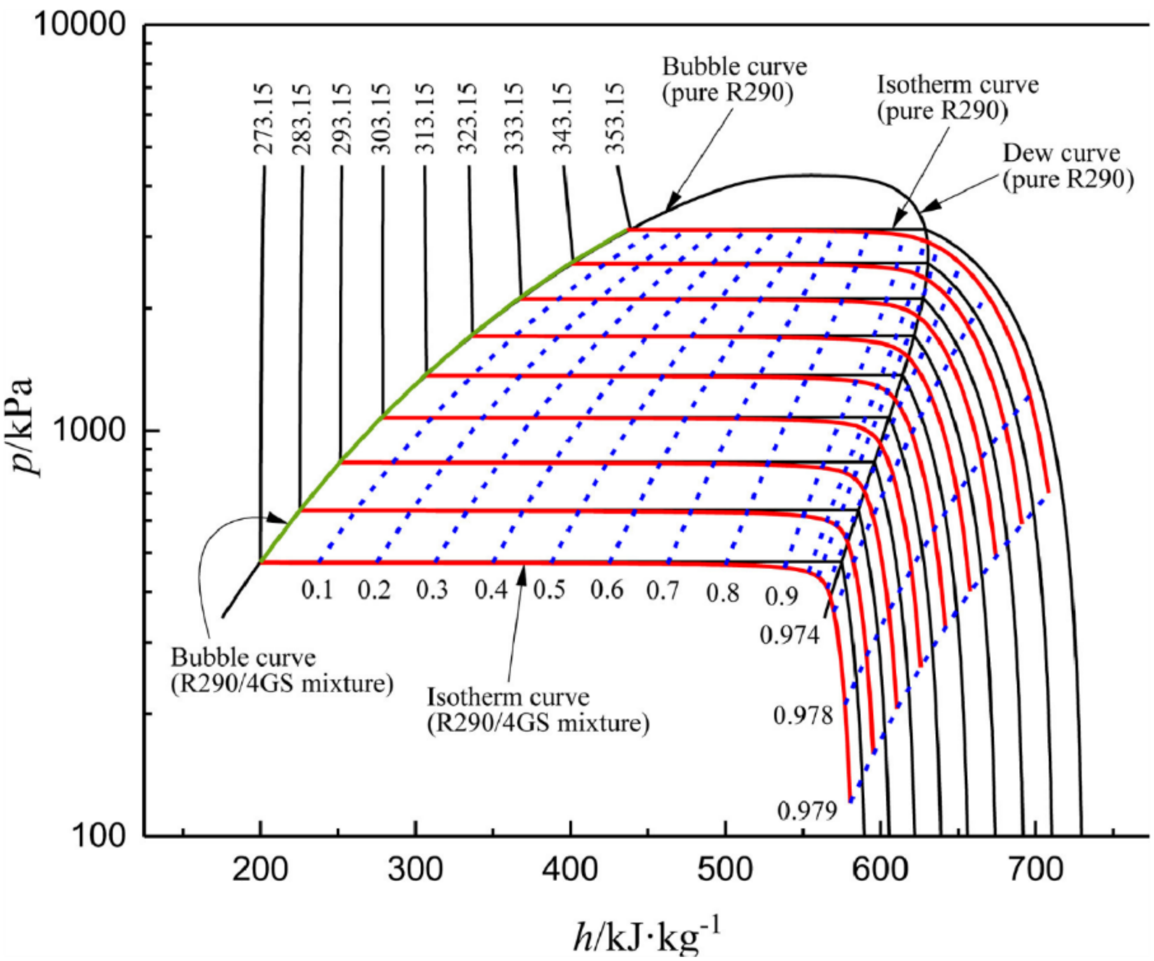


**Figure 4: Enthalpy diagram for a 4% mixture of R290 and 3GS mineral oil *(Image courtesy of Wang et al., 2021)***

Figure 4 shows the log(P)-h diagram for a mixture of R290 and mineral oil 3GS for oil circulating mass fraction of 4% [8]. The figure illustrates the thermodynamic behavior of the working fluid, with black lines representing pure refrigerants and red lines corresponding to the refrigerant–oil mixture. It clearly demonstrates that, unlike pure refrigerants, the vapor line in the vapor–liquid mixture region is less distinct when oil is present, as the oil tends to remain in the liquid phase throughout the process. During evaporation, two distinct regions can be identified. Initially, the mixture behaves similarly to a pure refrigerant, exhibiting isothermal characteristics in the early stages of the evaporator. However, as evaporation progresses and the local concentration of oil in the remaining liquid increases, the behavior begins to deviate. This results in a departure from the isothermal path, with the mixture curve approaching the vapor line of the pure refrigerant. This shift highlights the influence of oil accumulation on phase change behavior and heat transfer performance.

### Conclusions

Understanding the interactions between lubricants/oils and refrigerants is essential for optimizing the performance, reliability, and energy efficiency of HVAC and refrigeration systems. The presence of oil within the refrigerant circuit can significantly influence key thermophysical properties such as viscosity, boiling point, and heat transfer capacity, often leading to reduced system efficiency if not properly accounted for. Both miscibility and solubility play crucial roles in ensuring smooth oil circulation and preventing phase separation, particularly under varying temperature and pressure conditions. As the industry moves toward low-GWP refrigerants, careful selection and evaluation of mixtures combinations become increasingly important.

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