Computational Analysis Of An Oil Separator

K. Bhatia
Visteon Climate Control Systems

S. Pitla
Visteon Climate Control Systems

V. Khetarpal
Visteon Climate Control Systems

R15-4

Computational Analysis of an Oil Separator

K. Bhatia, S. Pitla, & V. Khetarpal
Visteon Climate Control Systems
45000 Helm Street, Plymouth, MI 48170, USA

Introduction

The performance and durability of an automotive air-conditioning system are very important to such system suppliers as well as auto-manufacturers for obvious reasons of reduced warranty costs and quality assurance. Typically, an automotive air-conditioning system consists of a compressor, two heat exchangers, an expansion device, an accumulator, and refrigerant. The durability of compressor is affected by providing adequate lubrication to its moving parts with oil. However, thermal performance of heat exchangers, especially an evaporator where boiling heat-transfer coefficient and mean temperature difference, is sensitive to oil concentration [1]. Therefore, it is desirable to separate oil from the refrigerant just downstream of the compressor discharge and reefed into the suction side. Oil separator can be used for separating oil from the refrigerant-oil mixture. Oil separators can be classified as: impingement, coalescing, and centrifugal types [2]. Impingement type lead to significant pressure drops if not designed carefully. Coalescing type is expensive, while, centrifugal type can be used without much penalty of pressure drop. In this study, a centrifugal oil separator is chosen for analysis. Figure 1 shows a schematic of such an oil separator mounted integrally with a compressor.
The purpose of this paper is to present a numerical approach to analyze and better-design oil separators for minimum pressure drop and maximum separation efficiency.

Analysis

In the present study, a computational method is proposed to analyze an oil separator (hence a better design) for an automotive air-conditioning system. The present analysis is based on the following assumptions:

a) refrigerant and oil flows are incompressible within the oil separator
b) there is no inter-phase mass transfer between refrigerant and oil
c) oil-droplets have an average diameter, which can be calculated in a weighted-average manner
d) the mixture flow is basically isothermal, i.e., refrigerant and oil properties can be calculated at an average discharge pressure and temperature
e) steady state analysis is performed for the reported calculations

Generally, for multiphase flow of this type, there is a primary or carrier phase (refrigerant) and the other is secondary phase (oil). The mass fraction of oil in the mixture varies between 3 and 10%. Based on the above assumptions, two multiphase models have been used in this study. A brief description of each is presented here, while more details can be obtained from the User's Manual [3] provided by FLUENT.

Mixture or Algebraic Slip Multiphase Model

In this mixture model, phases can move at different velocities, but assume local equilibrium over short spatial length scales. In this model, the continuity equation and momentum equations of mixture are solved. In these equations, mass-averaged velocity, density, and viscosity are used. The momentum equation for mixture is obtained by summing the individual momentum equations for both phases employing mixture viscosity. Moreover, an extra term in momentum equation accounts for the momentum interaction between two phases due to the drift velocity (difference between a phase and mixture velocity) for secondary phase. Another velocity, termed as slip velocity, is defined as the velocity of the secondary phase relative to that of the primary phase. The drift and slip velocities are further related. The basic assumption of this model is that, to prescribe an algebraic relation for the relative velocity, a local equilibrium between phases should be reached over short spatial length scales. Based on this, secondary phase acceleration and particulate relaxation time are evaluated. Relaxation time, also a function of the particle diameter, is used to calculate the drag force on the secondary phase. Also solved is the volume fraction equation for each secondary phase in the domain of interest.

Eulerian-Eulerian Multiphase Model

In this model, additional conservation equations, in comparison with the single phase or mixture models, are solved. These additional conservation equations are modified by introducing the volume fractions for each phase, as well as mechanism for exchange of momentum between phases. A single pressure is used for each phase. Continuity and momentum equations are solved for each phase. Furthermore, volume fraction equations are solved for each phase. Momentum interaction between phases is evaluated using relaxation time and other forces like lift and virtual mass can also be included. Due to solution of additional equations, the turn-around time for solution is slower than the mixture model. The convergence behavior of this model is different from that of the mixture model if the turbulence modeling is used for both phases separately.

Results

The aim of this paper is to study the effectiveness of separation of oil from a mixture flow of refrigerant and oil. The primary flow phase is refrigerant and the secondary phase is oil. The domain used to illustrate the performance of two models is shown in Figure 2. The overall dimensions of the outer cylinder are 25 mm diameter and 60 mm long. A mixture inlet is shown towards the top of the cylinder. The flow swirls around the outer periphery of inner cylinder, which is about 7 mm in diameter with a small thickness. The refrigerant leaves this separator through inner diameter of the inner cylinder. The oil outlet hole, nearly 2 mm diameter, is provided at the bottom of the outer cylinder. This domain of interest is discretized using nearly 200000 hexahedral elements.

The input parameters involve specifying a mixture mass flow rate at the inlet, mass fraction of oil, turbulence intensity, gravitational constant, and a choice of multiphase method. Here, two mass flow rates (0.8 and 1.6 kg/min.), inlet oil mass fraction of 10% , 1% turbulence intensity, and a gravitational vector with magnitude of 9.81 m/s^2 are used for both models. Another input parameter is the size of oil particles. For this study, a constant diameter of 50 microns is chosen. Also provided are physical properties of refrigerant and oil at a typical discharge conditions from a compressor. Refrigerant density of 70 kg/m^3 and viscosity of 2.2e-05 PaS are used, while the corresponding properties for oil are 950 kg/m^3 and 0.015 PaS.

As described above, both the mixture and Eulerian models are employed in this study. The standard k-ε turbulence model with wall functions is used. In Eulerian model, it is possible to solve turbulent flow equations for individual phases or mixture. It is observed through a number of cases run that it suffices to apply turbulence model to the mixture for better convergence.

Figure 3 shows the velocity vectors on a vertical plane and a plane through the inlet section for the mixture model at higher flow rate case. It can be observed from this figure that the mixture swirls around the inner cylinder and a bulk of the flow escapes through inner side of the inner cylinder. Figure 4 shows contours of oil concentration on two central vertical planes. The heavier oil particles drop down and exit through the oil hole at the bottom of the cylinder. As shown in this figure, the oil concentration at the bottom of the cylinder is nearly 1.0, which indicates that there is 100% oil. Figure 5 shows contours of pressure on a central vertical plane.

A summary of results for both the models at two flow rates are presented in Table 1. It is observed that mass flow rates through the oil hole are comparable at both flow rates. 14 to 15 % of total outflow is through the oil hole. The next column in this table shows a pressure drop between the inlet and outlet of the domain for both flow rates. A comparison between two models shows a difference of about 15%. This difference may be attributed to inherent assumptions of the mixture model.

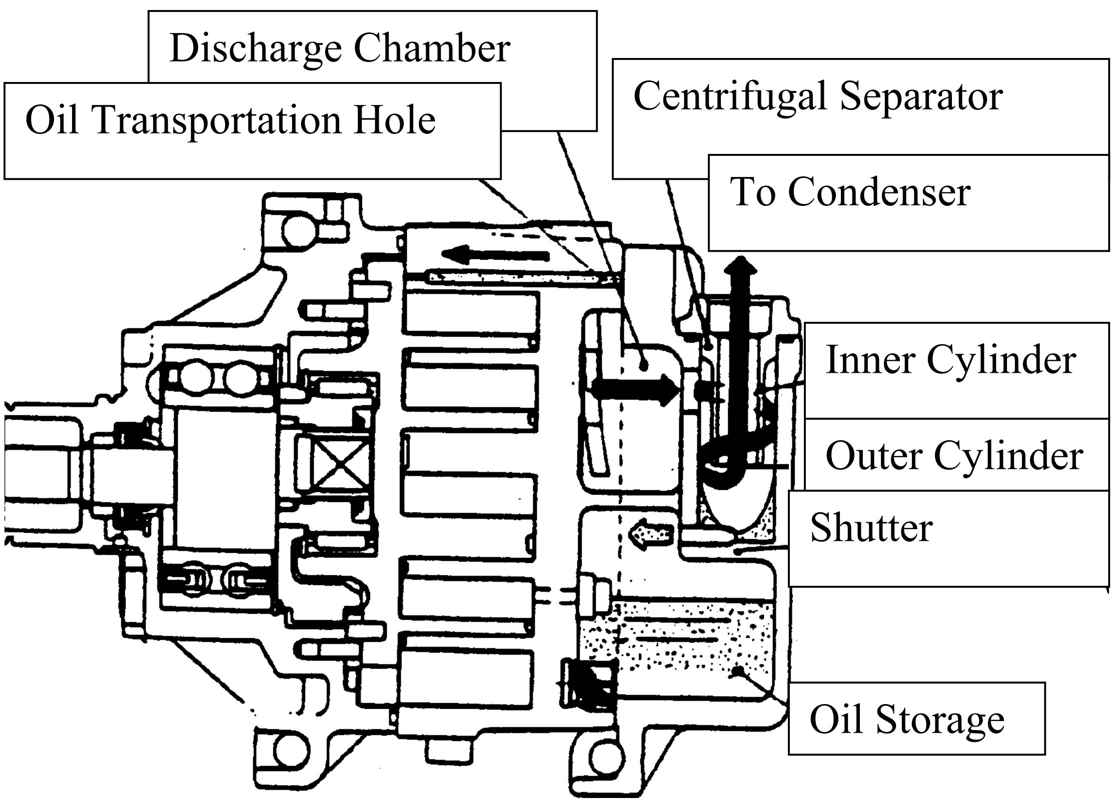

Figure 1: A schematic of an integrated oil separator in a compressor [4]

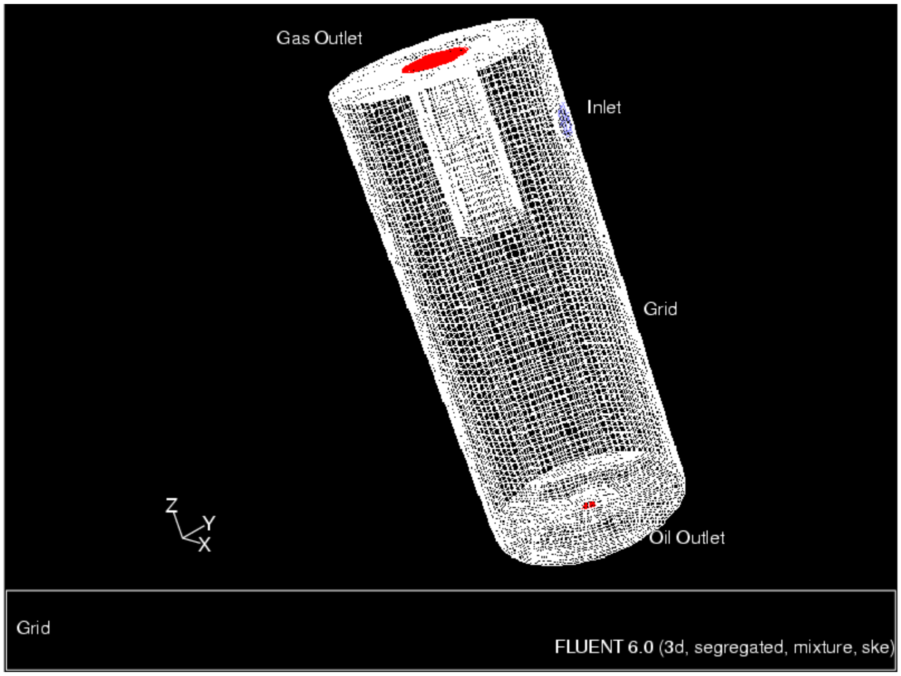

Figure 2: Discretized oil separator domain showing the mixture inlet, refrigerant and oil outlets

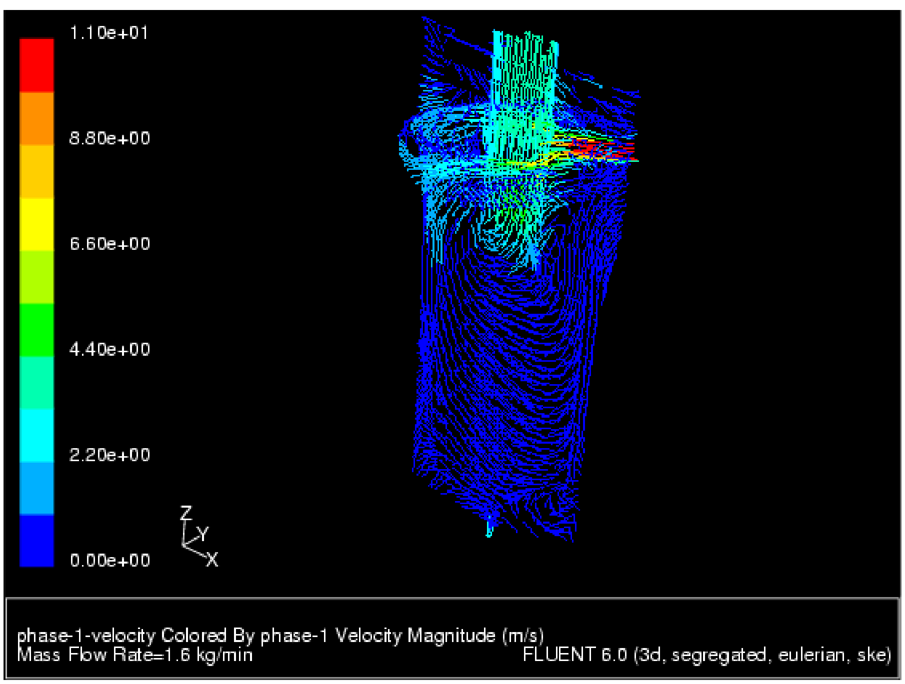

Figure 3: Velocity vectors on a central vertical and mixture inlet planes for the Eulerian model with a mass flow rate of 1.8 kg/min.

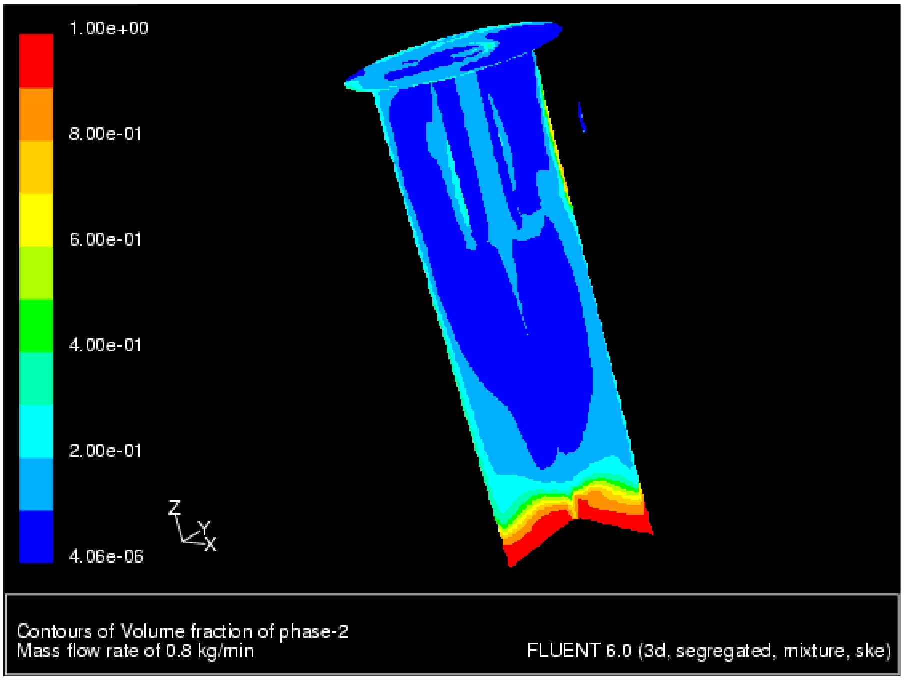

Figure 4: Contours of oil concentration on two central perpendicular and gas outlet planes for the mixture model with a mass flow rate of 0.8 kg/min.

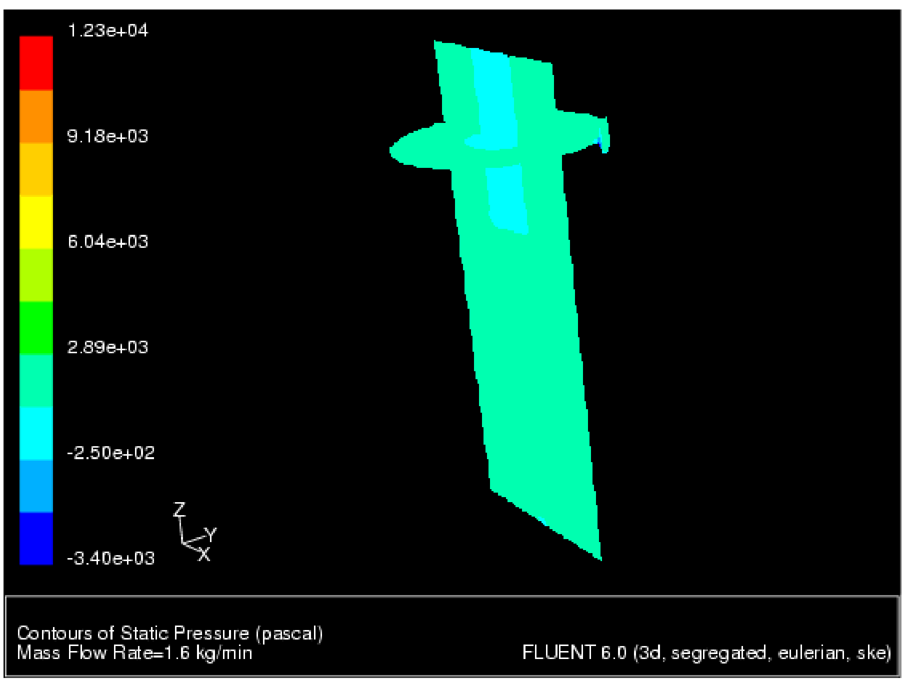

Figure 5: Contours of pressure distribution on a central and mixture inlet planes for the Eulerian model with a mass flow rate of 1.6 kg/min.

Model	Mass Flow – Inlet (kg/min)	Mass Flow – Oil Outlet (kg/min)	Pressure Drop (Pa)	Effective Particle Diameter (microns)
Mixture Model	0.8	0.120	580	50
Eulerian Model	0.8	0.119	495	50
Mixture Model	1.6	0.236	2296	50
Eulerian Model	1.6	0.220	1970	50

Table 1: Comparison of oil mass flow rates and corresponding pressure drops for mixture and Eulerian models at different mixture mass flow rates.

Conclusions

Based on two computational schemes, a method to analyze an oil separator has been presented. It is concluded that two multiphase models yielded consistent results. For the analyzed centrifugal oil separator, pressure drop is found to be reasonably small. The algebraic slip or mixture model is computationally cheap. Eulerian model is more robust and lift force and inertial effects on the particles can also be applied using experimental data, if available. The convergence behavior of this model can be affected by a choice of employing turbulence model to individual phases or to the mixture.

References

[1] Thome, J. R., Comprehensive Thermodynamic Approach to Modeling Refrigerant -Lubricating Oil Mixtures; HVA&C Research April 1995
[2] Barr, Robert, Re-thinking oil separators, Store Equipment & Design; August 1997
[3] User's Manual, Fluent V6, Fluent Inc.; 2002
[4] Akiyama,Y. & Watanabe, Y.; Development of Scroll Type Compressor with built-in Oil Separator SCS08; 1998