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(54) Titre : FLUIDES HYDRAULIQUES CONTENANT UN AMELIORATEUR DE LA VISCOSITE D'UN POLYALKYL(METH)ACRYLATE A UTILISER DANS LES PROCEDES DE MOULAGE DE PLASTIQUE PAR INJECTION

(54) Title: HYDRAULIC FLUIDS CONTAINING A POLYALKYL(METH)ACRYLATE VISCOSITY IMPROVER FOR USE IN PLASTIC INJECTION MOLDING PROCESSES

(57) Abrégé/Abstract:
The present invention relates to the use of hydraulic fluids in plastic injection molding processes (PIM). The use of hydraulic fluids with the right combination of physical parameters such as viscosity grade, viscosity index, density and dispersancy allows for significant energy savings in plastic injection molding processes. The invention provides a hydraulic fluid composition comprising a polyalkyl(meth)acrylate viscosity index improver consisting of monomer units of ethylenically unsaturated ester compounds and a base oil, the formulated hydraulic fluid having a fresh oil viscosity index of at least 160, a viscosity at 40°C of 15 mm^2/s to 51 mm^2/s, and a density at 15°C of 800 kg/m^3 to 860 kg/m^3.

Abstract

The present invention relates to the use of hydraulic fluids in plastic injection molding processes (PIM). The use of hydraulic fluids with the right combination of physical parameters such as viscosity grade, viscosity index, density and dispersancy allows for significant energy savings in plastic injection molding processes. The invention provides a hydraulic fluid composition comprising a polyalkyl(meth)acrylate viscosity index improver consisting of monomer units of ethylenically unsaturated ester compounds and a base oil, the formulated hydraulic fluid having a fresh oil viscosity index of at least 160, a viscosity at 40°C of 15 mm^2/s to 51 mm^2/s, and a density at 15°C of 800 kg/m^3 to 860 kg/m^3.

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Hydraulic fluids containing a polyalkyl(meth)acrylate viscosity improver for use in plastic injection molding processes

Technical field of the Invention

The present invention relates to the use of hydraulic fluids in plastic injection molding processes. Thereby it was surprisingly found that the use of hydraulic fluids with the right combination of physical parameters like the viscosity grade, the viscosity index, the density and the dispersancy allows for significant energy savings in plastic injection molding processes (PIM). The PIM process is an industrial process to manufacture plastic parts at well controlled temperatures, pressures and cycle times. The energy consumption of the process became more important over the last years, however, other parameters like process stability and accuracy of plastic part parameters as well as machine protection and long oil drain intervals have to be satisfying.

Background of the Invention

Injection molding is a manufacturing process for producing parts by injecting material into a mould at well controlled temperatures, pressures and cycle times. Injection moulding can be performed with a host of materials, including metals, glasses, elastomers, confections, and most commonly thermoplastic and thermosetting polymers. Material for the part is fed into a heated barrel, mixed, and forced into a mold cavity, where it cools and hardens to the configuration of the cavity.

The power required for this process of injection molding depends on the various movements in the molding machine, but also varies between materials used. The book *Manufacturing Processes Reference Guide* from Robert Todd states that the power requirements depend on a material's specific gravity, melting point, thermal conductivity, part size, and molding rate. Injection moulding machine is actuated by hydraulic system, wherein the electrical energy is transformed into mechanical energy through hydraulic energy. The energy reaches the actuators in the form of pressure and volume flow. While transmitting power through hydraulic forces, a loss of energy is observed due to flow losses and friction. In addition, the compression of hydraulic fluid develops frictional heat, which has to be controlled for example by cooling. Pump type and control of that pump also contribute heavily to how efficient a molding machine is in processing the plastic.

In the state of the art some efforts were made to save energy by modification of the injection molding machines. In EP 0 403 041 for example special alternating-current servo motors for the pumps which are connected to the hydraulic consumers are used. In US 4,020,633 a completely new concept for the whole hydraulic drive system of the injection molding machine is disclosed. But none of these concepts touches the hydraulic fluid that is used here. Therefore it must be possible to realize additional energy savings by optimizing these fluids.

EP 2337832 discloses a method of reducing noise generation in a hydraulic system, comprising contacting a hydraulic fluid comprising a polyalkyl(meth)acrylate polymer with the hydraulic system. The hydraulic fluid has a Viscosity Index VI of at least 130. The polyalkyl(meth)acrylate has a molecular

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weight in the range of 10 000 to 200 000 g/mol and is obtained by polymerizing a mixture of olefinically unsaturated monomers, said mixture comprising preferably 50 to 95 wt% C_9 to C_{16} and 1 to 30 wt% of C_1 to C_8.

Target of the invention described in EP 2337832 was the reduction of noise which is achieved by increasing oil viscosities at higher temperatures. For this effect high viscosities and high densities are beneficial and the high VI of the fluids is used to increase the viscosity at the operating temperature.

In the present invention a completely different approach is used to increase the energy efficiency. A high VI is used to enable a reduction of the base fluid viscosity. This reduced viscosity in combination with a low density of the hydraulic base fluid increases the efficiency of the injection molding process. In comparison to EP 2337832 it is not expected that hydraulic fluids according to the present invention decrease the noise level.

EP 2157159 discloses a hydraulic fluid containing, as a base oil, an ester containing at least two ring structures. It is described that the hydraulic fluid has low energy loss due to compression and exhibits excellent responsiveness when being used in a hydraulic circuit. Consequently, the hydraulic fluid realizes energy-saving, high-speed operation and high precision of control in the hydraulic circuit.

EP 1987118 discloses the use of a fluid with a viscosity improving index of at least 130 for the use in hydraulic systems like engines or electric motors. This fluid comprises a copolymer of C_1 to C_6 (meth)acrylates, C_7 to C_{40} (meth)acrylates and optionally further with (meth)acrylates copolymerizable monomers in a mixture of an API group II or III mineral oil and a polyalphaolefine with a molecular weight below 10,000 g/mol. It is neither shown here that such a fluid is also usable in an injection molding machine nor which specific composition of the fluid would be applicable in such a machine.

However, there still exists a need to investigate further on possible alternative hydraulic fluid compositions to be used in a hydraulic system subject to high working pressure, like in plastic injection molding processes.

Object

The improvement of energy efficiency is a common object in the technical field of injection molding. Usually such objects are achieved by construction improvements of the unit providing mechanical energy of the hydraulic system. However, there is still a need for further improvements with regard to that object. Accordingly, the purpose of the present invention was to provide a method for saving energy, increase productivity, avoid heating, improve air release and avoid cavitation over a broad temperature operating window in a hydraulic system used in plastic injection molding processes.

Especially was the object of the present invention to improve the performance of a hydraulic system in a plastic injection molding machine with energy savings of at least 5% and of up to 10%, compared to the performance of a machine when run with a standard fluid having a VI around 100 as recommended

by the producers of injection molding machines. It was also object to realize an energy saving for single, very energy consuming process steps of more than 10%.

Especially it was the object of the present invention to realize this energy saving by providing a new hydraulic fluid for the use in plastic injection molding machines.

Further objects not explicitly discussed here may become apparent herein below from the prior art, the description, the claims or exemplary embodiments.

Description of the Invention

The above-indicated prior art documents relating to injection molding processes try to reduce energy consumption, but without changing oil parameters. After an exhaustive investigation, the inventors have unexpectedly found that the hydraulic fluid plays a crucial role for saving energy in plastic injection molding processes, and in particular that some hydraulic fluid compositions adjusted to the right physical parameters, allow for energy savings of up to 5 % or more in the overall plastic injection molding process (PIM), or more than 10 %, mostly up to 15 % for certain step of the PIM process. Indeed, by adjusting the viscosity grade, the viscosity index, the density and dispersancy of the hydraulic fluid in accordance with the present invention, the inventors have found that a significant amount of energy can be advantageously saved, even by operating at high pressure conditions as it is usual in PIM processes.

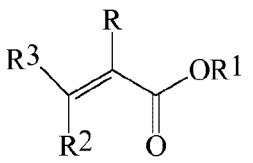
In detail, the objects discussed above have been solved by a novel method of reducing the energy consumption of a hydraulic system in an industrial hydraulic application, preferably in a plastic injection molding process or in a process comprising a hydraulic press. In this method a hydraulic fluid is used in a plastic injection molding process. The hydraulic fluid composition thereby comprises (i) a polyalkyl(meth)acrylate viscosity index improver and (ii) a base oil.

The polyalkyl(meth)acrylate viscosity index improver (i) thereby comprises at least monomer units a) and b) and optionally monomer units c) and/or d). Preferably the component (i) has a weight average molecular weight (M_w) from 20,000 to 100,000 g/mol. More preferred the molecular weight M_w is between 30,000 and 85,000 g/mol and especially preferred between 40,000 and 70,000 g/mol. The polydispersity index of the polyalkyl(meth)acrylate viscosity index improver is between 1 and 4, preferred between 1.2 and 3.0 and most preferred between 1.5 and 2.5.

The polyalkyl(meth)acrylate viscosity index improver (i) contains 5 to 40 wt.%, preferred 7 to 30 wt.%, more especially preferred 10 to 25 wt.% of repeating units that have been obtained by the copolymerization of monomers a) and 50 to 95 wt.%, preferred 60 to 93 wt.%, more especially preferred 70 to 90 wt.% of repeating units that have been obtained by the copolymerization of monomers b). In a special embodiment of the invention the amount of the compound of formula (II) is between 75 and 90 wt.%, especially preferred between 70 and 80 wt.%.

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Monomers a) thereby are one or more ethylenically unsaturated ester compounds of formula (I)



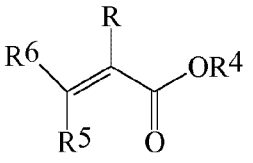
(I)

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wherein R is equal to H or CH_3, R^1 represents a linear or branched alkyl group with 1 to 6 carbon atoms and R^2 and R^3 independently represent H or a group of the formula -COOR', wherein R' is H or an alkyl group with 1 to 5 carbon atoms.

Examples of component a) are, among others, (meth)acrylates, fumarates and maleates, which derived from saturated alcohols such as methyl (meth)acrylate, ethyl (meth)acrylate, n-propyl (meth)acrylate, isopropyl (meth)acrylate, n-butyl (meth)acrylate, tert-butyl (meth)acrylate and/or pentyl (meth)acrylate; cycloalkyl (meth)acrylates, like cyclopentyl (meth)acrylate. Methacrylates are even preferred over acrylates.

Monomers b) are one or more ethylenically unsaturated ester compounds of formula (II)



(II)

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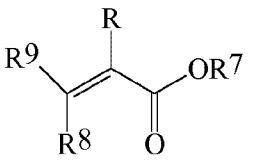
wherein R is equal to H or CH_3, R^4 represents a linear or branched alkyl group with 7 to 15 carbon atoms and R^5 and R^6 independently represent H or a group of the formula -COOR'', wherein R'' is H or an alkyl group with 6 to 15 carbon atoms.

Among these are (meth)acrylates, fumarates and maleates that derive from saturated alco-hols, such as n-hexyl (meth)acrylate, 2-ethylhexyl (meth)acrylate, heptyl (meth)acrylate, 2-tert-butylheptyl (meth)acrylate, octyl (meth)acrylate, 3-isopropylheptyl (meth)acrylate, nonyl (meth)acrylate, decyl (meth)acrylate, undecyl (meth)acrylate, 5-methylundecyl (meth)acrylate, dodecyl (meth)acrylate, 2-methyldodecyl (meth)acrylate, tridecyl (meth)acrylate, 5-methyltridecyl (meth)acrylate, tetradecyl (meth)acrylate and/or pentadecyl (meth)acrylate.

The polyalkyl(meth)acrylate viscosity index improver (i) may also contain further components that are in form of a monomer copolymerizable with at least one of the components a) and b). These further monomers are especially the components c) and d), with c) in a maximal concentration of 30 wt.% and d) in a maximal concentration of 10 wt.%.

Monomers c) thereby represent one or more ethylenically unsaturated ester compounds of formula (III)

(III)



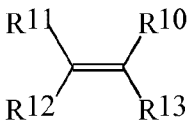
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wherein R is equal to H or CH_3, R^7represents a linear or branched alkyl group with 16 to 30 carbon atoms and R^8 and R^9 independently represent H or a group of the formula –COOR'", wherein R'" is H or an alkyl group with 16 to 30 carbon atoms.

Examples of component c) are, among others, (meth)acrylates, fumarates and maleates, which derived from saturated alcohols such as 2-methylhexadecyl (meth)acrylate, heptadecyl (meth)acrylate, 5-isopropylheptadecyl (meth)acrylate, 4-tert-butyloctadecyl (meth)acrylate, 5-ethyloctadecyl (meth)acrylate, 3-isopropyloctadecyl (meth)acrylate, octadecyl (meth)acrylate, nonadecyl (meth)acrylate, eicosyl (meth)acrylate, cetyleicosyl (meth)acrylate, stearyleicosyl (meth)acrylate and/or docosyl (meth)acrylate.

Optionally, the the polyalkyl(meth)acrylate viscosity index improver (i) contains 5 to 20 wt.% of the monomers a), 70 to 90 wt.% of the monomers b) and 2 to 25 wt.% of the monomers c) in polymerized form.

Monomers d) are at least one N-dispersant monomer. Preferred this N-dispersant monomer is of the



formula (IV) ,

wherein R^{10}, R^{11} and R^{12} independently are H or an alkyl group with 1 to 5 carbon atoms and R^{13} is either a group C(Y)X-R^{14} with X = O or NH and Y is (=O) or (=NR^{15}), where R^{15} is an alkyl or aryl group. R^{14} represents a linear or branched alkyl group with 1 to 20 carbon atoms which is substituted by a group $NR^{16}R^{17}$, where R^{16} and R^{17} independently represent H or a linear or branched alkyl group with 1 to 8 carbon atoms, or wherein R^{16} and R^{17} are part of a 4 to 8 membered saturated or unsaturated ring containing optionally one or more hetero atoms chosen from the group consisting of nitrogen, oxygen or sulfur, wherein said ring may be further substituted with alkyl or aryl groups.

Alternatively R^{13} is a group $NR^{18}R^{19}$, wherein R^{18} and R^{19} are part of a 4 to 8 membered saturated or unsaturated ring, containing at least one carbon atom as part of the ring which forms a double bond to a hetero atom chosen from the group consisting of nitrogen, oxygen or sulfur, wherein said ring may be further substituted with alkyl or aryl groups.

Preferably, said dispersant monomer d) of polymer (i) is at least one monomer selected from the group consisting of N-vinylic monomers, (meth)acrylic esters, (meth)acrylic amides, (meth)acrylic imides each with N-containing, dispersing moieties in the side chain. In particular it is preferred that the N-dispersant monomer is at least one monomer selected from the group consisting of N-vinyl pyrrolidone, N,N-dimethylaminoethyl methacrylate and N,N-dimethylaminopropylmethacrylamide.

Optionally the polyalkyl(meth)acrylate viscosity index improver (i) contains 5 to 25 wt.% of the monomers c) and 1 to 7 wt.% of the monomers d), both in polymerized form. Especially the viscosity index improver (i) contains 10 to 20 wt.% of the monomers c) and 2 to 5 wt.% of at least one N- dispersant monomer d) in polymerized form.

For this invention the base oil (ii) is selected from API group I, II, III or IV base oils or a mixture thereof. By using one of these base oils or mixtures of at least two of these base oils together with the viscosity index improver (VII) described above the formulated hydraulic fluid of this invention has a fresh oil viscosity index of at least 160, a viscosity at 40°C of 15 cSt to 51 cSt and a density at 15°C of 800 kg/m^3 to 890 kg/m^3. Especially preferred are API group IV base oils in form of polyalphaolefin (PAO) or mixtures of API group I to IV base oils containing at least 50 wt.% polyalphaolefins.

Synthetic hydrocarbons, especially polyolefins are well known in the art as API group IV base oils. These compounds are obtainable by polymerization of alkenes, especially alkenes having 3 to 12 carbon atoms, like propene, 1-hexene, 1-octene, 1-decene and 1-dodecene, or mixtures of these alkenes. Preferred PAOs have a number average molecular weight in the range of 200 to 10000 g/mol, more preferably 500 to 5000 g/mol.

In particular the hydraulic fluid composition comprises 70 to 95 wt.%, more preferably 80 to 95 wt.% and even more preferably 80 to 90 wt.% of the base oil (ii) selected from API group I, II, III or IV base oils or mixture thereof and 5 to 30 wt.%, more preferably 5 to 20 wt.% and even more preferred 10 to 20 wt.% of the polyalkyl(meth)acrylate viscosity index improver (i). Especially suitable are hydraulic fluids corresponding to this invention having a viscosity index of at least 180, preferred of at least 200, especially preferred of at least 250 and a viscosity at 40°C of 15 cSt to 36 cSt, preferred between 15 cSt and 28 cSt, especially preferred between 19 cST and 28 cST. Furthermore it is advantageous, if the hydraulic fluid has a density at 15°C of 800 kg/m^3 to 860 kg/m^3, preferred of 800 kg/m^3 to 840 kg/m^3.

By calculating the hydraulic fluid composition it has to be considered that the viscosity index improver (VII) might be added in a solvent. In a preferred embodiment of this invention this solvent is also an API group I, II, III or IV oil. It is especially preferred that this solvent is identical to the base oil of the composition. Independently from the solvent that is used here it has to be calculated as part of the base oil in the composition. Usually the VII solution that is added contains 20 to 40 wt.% solvent.

The viscosity index can be determined according to ASTM D 2270.

The hydraulic fluid composition according to this invention may also contain a Dispersant-Inhibitor package (DI package) to improve parameters like foam, corrosion, oxidation, wear and others. This DI package may comprise antioxidants, antifoam agents, anticorrosion agents and/or at least one Phosphorous or Sulfur containing antiwear agent.

Technical benefits of this invention

High VI hydraulic fluids are typically applied in mobile applications such as excavators. In these applications the hydraulic fluid has to deal with a broad variety of temperatures – very low starting temperatures in winter and very high temperatures under heavy load conditions. The high VI of the fluid is required to keep the viscosity as close as possible to the optimum. The optimum is defined by the balance between mechanical efficiency which requires a thin oil and volumetric efficiency which requires a thick oil to minimize losses by internal leakage in the pump. In regular operating conditions and especially under heavy load conditions volumetric efficiency becomes the dominant factor and the viscosity index improver can greatly improve the efficiency by increasing the viscosity of the fluid.
The injection molding application is completely different compared to an excavator. The outside temperature is constant, the work cycle is well defined and heavy load conditions are avoided if possible. For this reason the oil temperature is rather constant and high VI base fluids are generally not used. Usually ISO46 monograde fluids are recommended by the producers of injection molding machines.

For these reasons it would not be expected to see an advantage of high VI fluids in an application as injection molding, but surprisingly we found significant energy savings when low-viscosity hydraulic fluids with high VI were used. Completely opposed to the well-described energy savings with high VI fluids in excavators the efficiency increase in injection molding is largest under low load conditions.

Surprisingly said method as defined above respectively in accordance with the present invention not only achieves the above-mentioned objectives, but also advantageously provides an increased oil life time with consequent longer drain intervals for the hydraulic system.

Furthermore, the system performance of the hydraulic system can be improved. The expression system performance means the work productivity being done by the hydraulic system within a defined period of time. Particularly, the system performance can be improved at least 5%, more preferably at least 10 %. In preferred systems, the work cycles per hour can be improved.

Synthesis of the viscosity index improver

For the synthesis of the polyalkyl(meth)acrylate viscosity index improver (i) the monomer mixtures described above can be polymerized by any known method. Conventional radical initiators can be used to perform a classic radical polymerization. These initiators are well known in the art. Examples for these

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radical initiators are azo initiators like 2,2'-azodiisobutyronitrile (AIBN), 2,2'-azobis(2-methylbutyronitrile) and 1,1 azo-biscyclohexane carbonitrile; peroxide compounds, e.g. methyl ethyl ketone peroxide, acetyl acetone peroxide, dilauryl peroxide, tert.-butyl per-2-ethyl hexanoate, ketone peroxide, me-thyl isobutyl ketone peroxide, cyclohexanone peroxide, dibenzoyl peroxide, tert.-butyl per-benzoate, tert.-butyl peroxy isopropyl carbonate, 2,5-bis(2-ethylhexanoyl-peroxy)-2,5-dimethyl hexane, tert.-butyl peroxy 2-ethyl hexanoate, tert.-butyl peroxy- 3,5,5-trimethyl hexanoate, dicumene peroxide, 1,1 bis(tert. butyl peroxy) cyclohexane, 1,1 bis(tert. butyl peroxy) 3,3,5-trimethyl cyclohexane, cumene hydroperoxide and tert.-butyl hydroperoxide.

Poly(meth)acrylates with a lower molecular weight can be obtained by using chain transfer agents. This technology is ubiquitously known and practiced in the polymer industry and is de-scribed in Odian, Principles of Polymerization, 1991.

Furthermore, novel polymerization techniques such as ATRP (Atom Transfer Radical Polymerization) and or RAFT (Reversible Addition Fragmentation Chain Transfer) can be applied to obtain useful polymers derived from alkyl esters. These methods are well known. The ATRP reaction method is described, for example, by J-S. Wang, et al., J. Am. Chem. Soc., Vol. 117, pp. 5614-5615 (1995), and by Matyjaszewski, Macromolecules, Vol. 28, pp. 7901-7910 (1995). Moreover, the patent applications WO 96/30421, WO 97/47661, WO 97/18247, WO 98/40415 and WO 99/10387 disclose variations of the ATRP explained above. The RAFT method is extensively presented in WO 98/01478, for example.

The polymerization can be carried out at normal pressure, reduced pressure or elevated pressure. The polymerization temperature is also not critical. However, in general it lies in the range of -20 to 200°C, preferably 60 to 120°C, without any limitation intended by this. The polymerization can be carried out with or without solvents. The term solvent is to be broadly understood here. According to a preferred embodiment, the polymer is obtainable by a polymerization in API Group I, II or III mineral oil or in API group IV synthetic oil.

Examples

The invention is illustrated further in the following non-limiting example and the comparative example (reference oil). The example below serves for further explanation of preferred embodiments according to the present invention, but are not intended to restrict the invention. All results are shown in Table 1 and Table 2.

Testing and Oils

For determining the energy consumption, different test oils were compared with a reference (ISO VG 46 monograde Castrol Hyspin™ DF Top 46, VI = 100).

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The following hydraulic fluids are used:

Table 1: Hydraulic fluid formulations

	Formulation		KV_{40} [mm^2/s]	KV_{100} [mm^2/s]	VI	density@15°C [kg/L]
Comparative Example 1	0.85% Hitec™ 521 8% Nexbase™ 3060 91.15% Nexbase 3080	Fresh oil: Fill for trial: After trial:	46.6 46.6 46.5	7.6 7.6 7.6	131 130 130	0.847
Comparative Example 2	Aral Forbex™ SE	Fresh oil: Fill for trial: After trial:	47.2 47.0 46.9	8.2 8.2 8.2	148 149 149	0.973
Reference Oil	Castrol Hyspin DF Top 46	Fresh oil: Fill for trial: After trial:	45.7 45.7 45.7	6.7 6.7 6.7	100 100 100	0.873
Example 1	5.8% PAMA-1 0.85% Hitec 521 21% Nexbase 3080 72.35% Nexbase 3060	Fresh oil: Fill for trial: After trial:	46.3 46.3 46.1	8.4 8.4 8.3	160 160 158	0.851
Example 2	14.2% PAMA-1 0.85% Hitec 521 17.45% Nexbase 3060 67.5% Nexbase 3043	Fresh oil: Fill for trial: After trial:	46.6 46.2 46.0	9.8 9.7 9.6	203 201 200	0.853
Example 3	8.8 % PAMA-1 DI package Nexbase 3043+3060	Fresh oil: Fill for trial: After trial:	32.0 32.1 32.3	7.0 7.0 7.0	189 189 189	0.842
Example 4	20% PAMA-2 DI package PAO-2	Fresh oil: Fill for trial: After trial:	25.7 25.8 25.7	7.5 7.5 7.4	285 283 281	0.831

The polyalkylmethacrylate viscosity index improver PAMA-1 consists of 13 wt.% of methyl methacrylate and 87 wt.% of C_{12-14} alkyl methacrylates (M_w = 52,000 g/mol, PDI = 2.1), dissolved in highly refined mineral oil.

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The polyalkylmethacrylate viscosity index improver PAMA-2 consists of 10 wt.% of methyl methacrylate and 90 wt.% of C_{12-15} alkyl methacrylates (M_w = 58,000 g/mol, PDI = 2.0), dissolved in highly refined mineral oil.

Properties	**Method**
Kinematic viscosity at 40°C, mm²/s	ASTM D445
Kinematic viscosity at 100°C, mm²/s	ASTM D445
VI	ASTM D2270
Density at 15°C, kg/L	ASTM D1298

The injection molding machine that was used to create the data was Krauss Maffei KM 80/380 CX. The energy consumption of the hydraulic pump was calculated by measuring voltage and current of the pump motor with external test equipment (measuring amplifier MX 840 PAKAP; element for voltage recording MX 403 B, 1000V; both from Hottinger Baldwin Messtechnik GmbH). Before testing the system was flushed with the hydraulic fluid to be used and the oil parameters were checked to ensure that the previous oil was properly purged and no mixing with previous oils occurred. Table 1 shows viscometric data for fresh oils, oil fill for trial and for the oil collected after the trial.

During testing, molding cycles were run with a PLEXIGLAS®-molding compound which was, in cycle A, covered with CoverForm® Reactive-Liquid cf30OA monomer mixture.

The evaluation of data has focussed on process steps without polymer to avoid any influence of polymer properties on the results.

Brief description of the drawings

Figure 1: Description of a typical injection molding cycle

The cycle begins when the mold closes (Step 1), followed by building up a pressure (Step 2a) which is required to keep the mold closed during injection. After moving the extruder to the mold (Step 2b), material is injected (Step 3) and a working pressure is maintained to compensate material shrinkage during molding (Step 4). Optionally, the work piece can be coated with a CoverForm® process step (Step 4.1, applied in Cycle A). The extruder is moved back when the cooling phase has started (Steps 5 and 6). At the end of the cooling phase the mold is opened (Step 7) and the work piece can be removed (Step 8).
Table 2 shows the differences in energy consumption (savings are negative values) found for cycle A, cycle B and an evaluation of Step 1 and Step 2 taken from cycle A data.

Cycle A: Step 1 + Step 2 (2a+2b) + Step 4.1 + Step 7 + Step 8
Cycle B: Step 1 + Step 2 (2a+2b) + Step 7 + Step 8

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Within this cycle, Steps 1, 2, 4.1, 7 and 8 are independent of the material which is injected. Consequently, the energy savings are independent on the plastic material properties.

The coating step 4.1 is optional and part of the CoverForm® process. Cycle A (with coating) and cycle B (without coating) evaluate the influence of this step on energy savings.

Table 2: Differences in energy consumption with investigated hydraulic fluids

	Comparative Ex 1	Comparative Ex 2	Ex 1	Ex 2	Ex 3	Ex 4
	Δ energy consumption versus reference oil [%]					
Cycle A	-	3.6	-4.9	-7.5	-6.7	-
Cycle B	2.5	5.1	-5.4	-7.9	-5.2	-9.5
Step 1 + Step 2	-	2.1	-7.0	-8.6	-5.7	-

Cycle A: process steps which are material independent, with CoverForm® process step
Cycle B: process steps which are material independent, without CoverForm® process step
Step 1 + Step 2: fully material independent steps before material injection

On the basis of the above results, it is clearly demonstrated that physical parameters of the base oil in combination with a viscosity index improver in accordance with the present invention are crucial in order to observe energy savings in an hydraulic system used under the high pressure conditions of a plastic injection molding process.

Although illustrated and described herein with reference to certain specific embodiments, the present invention is nevertheless not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope of the claims.

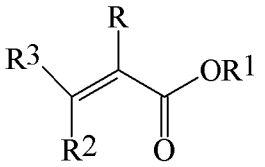
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The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of reducing the energy consumption of a hydraulic system, comprising applying a hydraulic fluid, in a plastic injection molding process, wherein the hydraulic fluid composition comprises:

(i) a polyalkyl(meth)acrylate viscosity index improver consisting of monomer units of:

a) 10 to 25 wt.% of one or more ethylenically unsaturated ester compounds of formula (I)



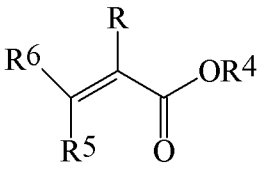
(I),

wherein R is equal to H or CH_3,

R^1 represents a linear or branched alkyl group with 1 to 6 carbon atoms,

R^2 and R^3 independently represent H or a group of the formula -COOR', wherein R' is H or an alkyl group with 1 to 5 carbon atoms, and

b) 75 to 90 wt.% of one or more ethylenically unsaturated ester compounds of formula (II)



(II),

wherein R is equal to H or CH_3,

R^4 represents a linear or branched alkyl group with 7 to 15 carbon atoms,

R^5 and R^6 independently represent H or a group of the formula -COOR'', wherein R'' is H or an alkyl group with 6 to 15 carbon atoms;

wherein

the weight average molecular weight (M_w) of the polyalkyl(meth)acrylate viscosity index improver (i) is 40,000 to 70,000 g/mol, and

(ii) a base oil which is an API group I, II, III or IV base oil or any mixture thereof,

wherein the formulated hydraulic fluid has:

a fresh oil viscosity index of at least 160;

a viscosity at 40°C of 15 mm^2/s to 51 mm^2/s; and

a density at 15°C of 800 kg/m^3 to 860 kg/m^3.

2. The method according to claim 1, wherein the hydraulic fluid has a density at 15°C of 800 kg/m^3 to 840 kg/m^3.

3. The method according to claim 1, wherein the hydraulic fluid has a viscosity index of at least 180, a viscosity at 40°C of 15 to 36 mm^2/s and a density at 15°C of 800 to 860 kg/m^3.

4. The method according to any one of claims 1 to 3, wherein the hydraulic fluid has a viscosity index of at least 200, a viscosity at 40°C of 15 to 28 mm^2/s and a density at 15°C of 800 to 840 kg/m^3.

5. The method according to any one of claims 1 to 4, wherein the hydraulic fluid has a viscosity index of at least 250, a viscosity at 40°C between 19 mm^2/s and 28 mm^2/s and a density at 15°C of 800 to 840 kg/m^3.

6. The method according to any one of claims 1 to 5, wherein the polyalkyl(meth)acrylate viscosity index improver comprises a polydispersity index of between 1.5 and 2.5.

7. The method according to any one of claims 1 to 6, wherein the hydraulic fluid composition comprises:

70 to 95 wt.% of the base oil which is an API group I, II, III or IV base oil or any mixture thereof; and

5 to 30 wt.% of the polyalkyl(meth)acrylate viscosity index improver.

8. The method according to claim 7, wherein the hydraulic fluid composition comprises:

80 to 95 wt.% of the base oil; and

5 to 20 wt.% of the polyalkyl(meth)acrylate viscosity index improver.

9. The method according to any one of claims 1 to 8, wherein the base oil comprises at least 50 wt.% polyalphaolefins.

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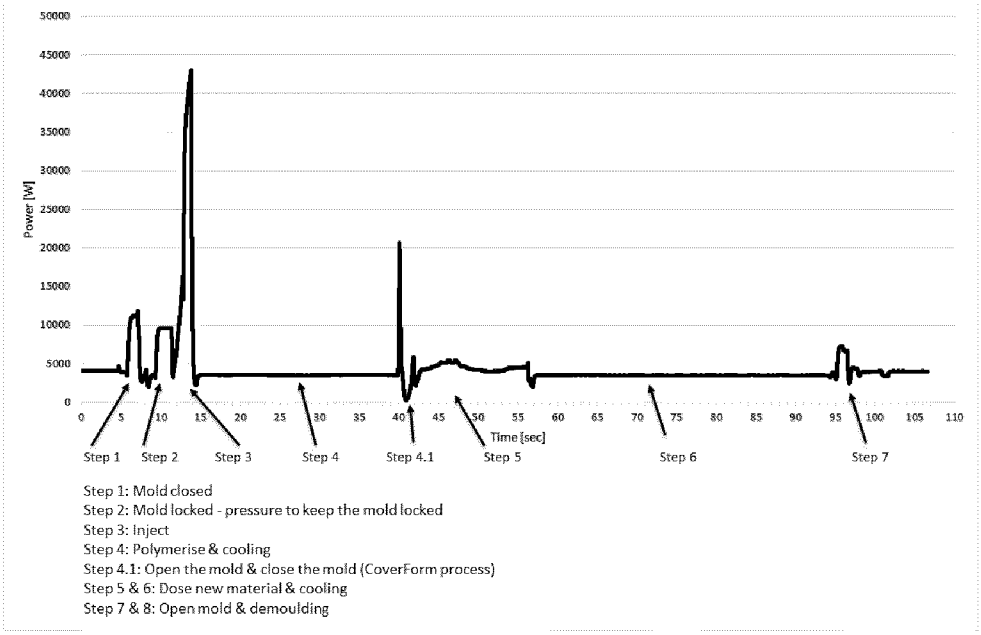
10. The method according to claim 9, wherein the polyalphaolefin has a number average molecular weight in the range of 200 to 10000 g/mol.

11. The method according to any one of claims 1 to 10, wherein the hydraulic fluid composition comprises:

a dispersant-inhibitor package comprising an antioxidant, an antifoam agent, an anticorrosion agent or at least one phosphorous- or sulfur-containing antiwear agent, or any combination thereof.

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Figure 1: Description of a standard injection molding cycle



Step 1: Mold closed
Step 2: Mold locked - pressure to keep the mold locked
Step 3: Inject
Step 4: Polymerise & cooling
Step 4.1: Open the mold & close the mold (CoverForm process)
Step 5 & 6: Dose new material & cooling
Step 7 & 8: Open mold & demoulding