Chapter

A Review on Electro-Rheological Fluid (ER) and Its Various Technological Applications

Sudipto Datta, Ranjit Barua and Jonali Das

Abstract

The technology of electro-rheological fluids is old, but now it is being used in market at high speed. In the near future, ER fluids may be used for structure design where accuracy, density and power density are primarily the main criteria. For minimizing the costs and maximizing the functionality of the products, like where the viscosity of the fluid is varied to design, solid structure ER fluids are used. Features like fast response and easy interface between electrical and mechanical input–output makes the ER fluid attractive to various technology fields. In this study, ER fluids' working principle, various low-cost ER fluids working procedures and ER fluid applications in multiple areas are explained.

Keywords: ER clutch, mechatronics, ER fluids, ER damper

1. Introduction

In electro rheological (ER fluids) the additive particles are kept in suspension in a dielectric fluid which is non-conducting. The Dielectric fluid, i.e., the Carrier fluid has high electrical resistivity and has a low viscosity like silicon oil, olive oil, hydrocarbons, etc. The additive particles which are mixed in the carrier fluids are mainly polymers, alumina silicates, metal oxides silica, etc. These additive particles commonly have low particles size which allows the carrier fluid to maintain low viscosity when the external electric field is not applied. In ER fluid the additive particles size range remains in 0.1–100 μm in the carrier fluid. Without any external electric field these fluids stays in liquid condition as soon as the external electric field is applied the ER fluid changes from liquid to solid by viscosity change of the fluid. In Electro rheological (ER) fluids a suspension of particles are present in a non-conducting fluid. The commonly used liquid i.e. hydrocarbon or silicon oil for suspension are low viscous and have high resistivity. Suspension particles are mainly polymers, alumina, silicates, metal oxides etc. These particles are present is very low concentration so that the viscosity of the suspending fluid remains low without application of the applied electric field. The suspension particles are dielectrics of size 0.1–100 μm. In absence of the electric field the particles exhibits properties like fluid and as the electric field is applied the particles behaves like solid. These fluids which change its physical properties like viscosity due to application of electric field are called electro rheological (ER) fluids or smart fluids. Types of ER or Smart fluids: (a) Electro Rheological (ER) Fluids—electric field changes the physical properties of the fluid,

(b) Magneto Rheological (MR) Fluids—magnetic fields changes the physical properties of the fluid, (c) Positive Electro Rheological (ER) Fluids—by application of the electric field the viscosity increases and (d) Negative Electro Rheological studied by Ko et al. [1] (ER) Fluids—by application of electric field the viscosity decreases. These ER fluids are one kind of smarts fluids. One of the most easily made ER fluid is adding corn flour in silicon oil or vegetable oil.

2. Electro rheological (ER) material interaction

When the electric field is applied on the ER fluid the suspension particles gets polarized and form a thick chain which is parallel to the electric field between the two electrodes. The thickness of the polarized suspension particles between the two electrodes is directly proportional to the intensity of the electric field. The rheological properties of the suspension depend on its change in structure. The more yield stress of the fluid is obtained from the particle columnar structure. When the electric field is removed the suspension particles polarization gets lost and the loose there structure and roam freely in the fluid which in turn reduces the viscosity. The period of returning from the solid state to the liquid state is few milliseconds upon removing the electric field. The material for electrorheological fluid is a superfine suspension of dielectric small particles which react to the applied electric field resulting in changing in the rheological properties of the ER fluid. There are three operational modes of the ER fluid which are as follows: (a) Flow mode—in this mode the electrodes are mounted and fixed and by controlling the motion of the flow the vibrational control is achieved, (b) Shear Mode—in this mode the vibrational control is achieved by varying the shear force here one electrode is fixed and the other is free for rotation and (c) Squeeze Mode—in this mode the space between the electrodes is changed which presses the ER fluid results with a normal force.

2.1 Properties or electrorheological (ER) fluid

In electro rheological fluids there is a large reversible change in the colloidal suspension rheological properties when subjected to the external electric field. Lots of studies are present in which the principle and the uses of the electrorheological fluid are presented by many researchers across the globe. Another property of the ER fluids is that the response time of the ER fluid is very quick for the applied electric fields so the band width is thick. **Figure 1** represents the effect of ER fluid particles when application of electric field. For this interesting property the ER fluid has more demand is carious technological applications like smart structure, shock absorbers, engine mount and machine mount. The yield stress of the ER fluid can also be varied by introduction of the external electric field that is why it is also known as functional fluid. Winslow [2] patented the invention of the ER fluid. This ER effect is introduced in state of art automobile. The ER effect was first invented in 1942 by Winslow [2] after that the details understanding of the EF effect took lots of time and then to find the suitable solution for the ER fluid effect took further more time. The properties which delays and stops the ER fluid in few application fields are temperature stability, yield stress and power consumption. Particles size, carrier fluid properties, density, temperature and additives of the ER fluids plays a vital role for most of the properties changes of the ER fluids.

There is a limit up to which the dispersing particles can be mixed with the fluid because by increasing the concentration of the dispersing particles volume fraction the electrorheological effect of the solution increases which also causes few problems. As increasing the concentration of the dispersing particle after a certain concentration

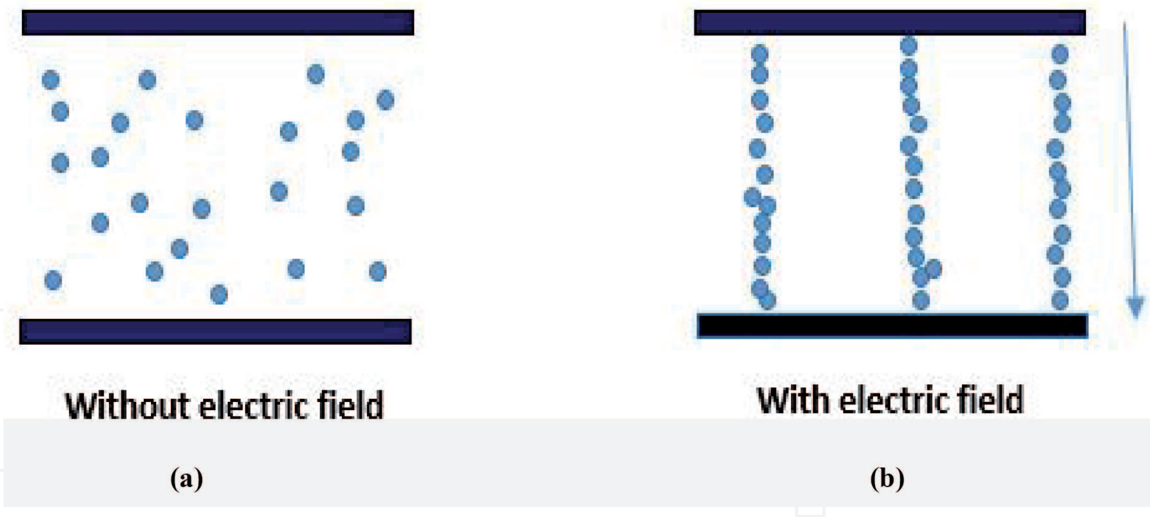

Figure 1.
(a) Dispersing particles without electric field, (b) dispersing particles with electric field.

limit the particles started settling down which cause a problem another problem which arises is the zero field viscosity increment. The viscosity is linked with the temperature i.e. the viscosity decreases when the temperature is increased. Temperature also decreases the dynamic yield strength. Mainly the change in the yield strength occurs due to relative permittivity and the conductivity of particle and also the chemical components of the fluid. Less amount of voltage approx. 1–4 KV/mm is needed for producing ER effect in the solution. 10^{-6} to 10^{-3} amp/cm^2 is the minimum needed current density for the ER effect. For calculating the power consumption of the suitable ER fluid the measurement of the current density are needed. Dynamic yield stress is one of the important ER fluid property, this stress is the maximum amount of stress required to flow the liquid when the electric field is applied. 100 Pa to 3 KPa is the range of the dynamic yield stress in current ER fluid. The comparison of the various ER fluids are still now difficult as because the standard testing procedure and the state for the fluid is not yet available properly and due to the dependency of the ER fluids on its dispersing particles and the fluid used combinations. For practical applications of the ER fluid the fluid must meet the desired criteria which are (a) Current density 4.0 KV/mm DC less than 10 μA/cm^2, (b) dynamic yield stress 4.0 KV/mm <3.0 KPa, (c) Zero field viscosity 0.1–0.3 Pas, i.e., 1–3 Poise, (d) Operational temp range −25°C to +125°C, (e) dielectric breakdown strength >50 KV/mm^2, (f) particle size 10 μm, (g) response time < millimeter, (h) Density 1–2 g/cm^3, (i) maximum energy density 0.001 Joule/cm^3, (j) power supply 2–5 KV@ 1–10 mA, (k) Any conductive surface material, (l) any opaque or transparent, and (m) physically and chemically stable with low conductivity and high breakdown voltage.

For shear loading state applications usually the ER materials are used. The relationship between the ER material and the share are shown in the **Figure 2**. In the year 1949 Winslow [2] invented the post-yield appearance of the ER effect. During that time the materials which behave like changing in viscosity were called electro-viscous fluids as their effective or actual viscosity changes were noticeable macroscopically. Many years after it was investigated that with the change in the applied electric field the apparent or the effective viscosity υ remains constant, only the noticeable change was found out was the yield stress of the Bingham plastic suspension. This is shown in **Figure 2**. Ideal plastic fluids are also another name given to the Bingham plastics, i.e., this fluid does not have viscosity (zero viscosity). A formula representing the shear stress exceeds the yield stress of the material is given by $\tau = \tau y + \vartheta\gamma$, where τ represents Shear stress, τy represents Yield Stress and $\vartheta\gamma$ represents Shear Strain. The behavior of the ER material the comparison of the

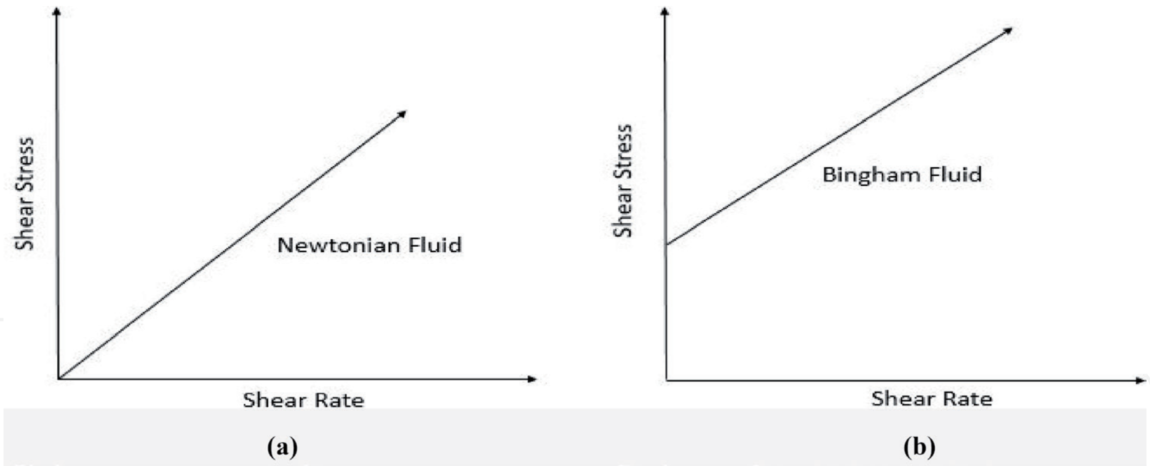

Figure 2.
Smart fluid characterization (a) without electric field and (b) with electric field.

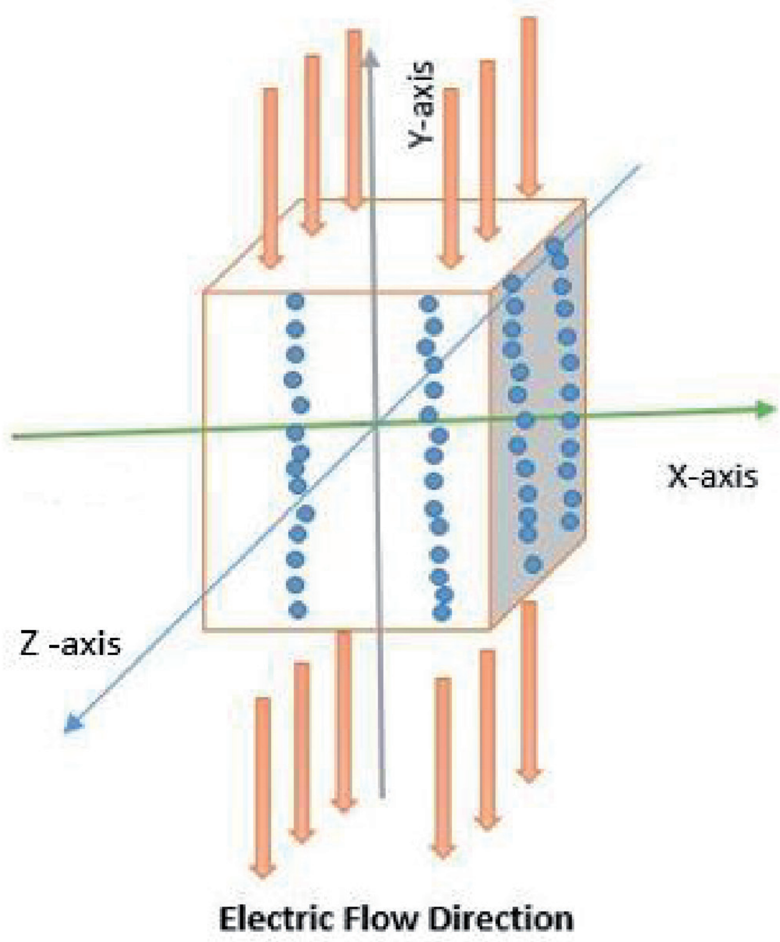

Figure 3.
Reaction of the ER fluid when external electric field is applied.

post yield behavior still not investigated. With increasing in the electric field the shear yield stress increases while the yield strain remains 1% for almost all fields. The reaction of the ER fluid on electric field is shown in **Figure 3**.

2.2 Typical carrier fluid and particles

The ER fluids which are available in the markets are very costly so here are few lists of combinations of the additive particles with the fluid to prepare the cost effective ER fluid. With suitable proportions and amount of the additive particle we can achieve the desired ER fluid as per our need. Various carrier fluids are aldehyde, grease, ketones, kerosene, aroclor, castor oil, chloroform, mineral oil, olefins, olive oil, dielectric oil, diphenyl sebacate, various ethers, resin oil, transformer oil, silicon oil etc. Various additive particles for the ER fluid are alfa silica, alginic acid, alumina, alfa methylacrylate, mannitol, boron, macrocel-C, carbon, cellulose, charcoal, chlorides, dyes, gypsum, micronized mica, nylon powder, olefins, porhin, pyrogenic silica, quartz, rubber, silica gel, etc. [3].

2.3 Preparation of ER fluids

ER fluid preparation procedure are very simple and mostly all the ER fluids are prepared by this manner the following procedure is used for preparing the ER fluids: (a) The desired powder is chosen and same particle powder size particles are required for the ER fluid dispensing particle, (b) the chosen powder must be passed through size sieve for all the particles same and must be weighted on the weighing machine, (c) the powder is poured in glass container and desired amount of the ER fluid is poured in the glass container which contains the powder of uniform size and are stirred continuously until the powder mixed with the fluid completely, (d) the mixture of the powder and the fluid are stirred for 2 h by glass rod or magnetic starrer at a constant RPM to get a uniform homogenous mixture, (e) the mixed solution is passed to a vane pump five times to get a good result homogenous solution and (f) this process should be followed for other ER solution preparation [3].

2.4 Testing and selection of ER fluids

The testing of the ER fluid is necessary for selecting of the desired ER fluid for the desired application. The following tests are mainly used (a) Temperature test, (b) breakdown test, (c) viscosity test and (d) sedimentation test.

2.5 Applications of electro rheological fluids

The electrorheological fluids which are totally dependent on the applied electric fields are used in resistive force creation and damping. Examples of applications are active vibration suppression and motion control. Wang et al. [4] have presented the uses of ER fluids in microfluidics [5]. Various industries like automobiles industries are demanding modified ER fluids with more efficiency Gurka et al. [6] introduced ER-Fluid RheOil®3.0 which improves the sedimentation and re-dispersing behavior. Brennan et al. [7] studied and distinguished the two classes of the ER dampers, first one acts by shearing the stationary fluid and the second one acts by pumping the ER fluid [5]. The two classes are described in details below. Most of the dampers of smart fluids have three common components, i.e., a cylinder, cylinder valve housing and a piston. The vibrating structure kinetic energy can be controlled and dissipated by providing either electric or magnetic field in the valve. In the ER damping process two types of frictions are used they are viscous and coulomb friction [8]. The columbic force denotes the friction acting when two surfaces comes in contact to each other like friction of bearing and hinges friction. Friction is independent to the body velocity, i.e., it is constant. To push fluids through narrow obstructive passage viscous friction comes into play these exists in valves and orifices and is body velocity dependent. The viscous friction and the columbic friction summation is the actuation friction which is denoted in **Figure 4**. These frictions have good effects also in the damping machines. The transmission of the vibration to the device is possible by dry sealing friction. For sensitive instruments small vibrations can cause poor accuracy [9]. Bad effect of the friction is also present in the system when the force applied is near to overwhelm the static friction this is known as motion of stick–slip.

At a near to zero velocity the stick–slip motion happens like an unexpected motion of jerking. Naturally, kinetic friction coefficient in between the two surfaces is smaller than the static friction coefficient. When the given force is more to overwhelm than the static friction then the friction decreases from static to dynamic. Because of this sudden decrease of the friction there will be a sudden velocity jump movement. To show this effect the system of two degree of freedom is taken.

2.5.1 Shear mode

In this type of mode of ER damper there are one or two parallel electrodes which can move parallel to each other and is always perpendicular to the electric field applied so that the fluid can have uniform shear and the ER fluid is present in between the two electrodes. From **Figure 5a** c and l are the breath and length of the electrode and j is the electrodes gap. Here E is given voltage, F is net damping force and V is the relative velocity of the electrodes. Two forces are acting in this ER damper (a) Active force Fc because of ER effect and (b) Passive force Fy due to the fluid viscosity. Fy, i.e., the passive force is always present and directly linked with the viscosity of the fluid as well as the damper geometric properties. During application of the electric field a force Fc (because of creation of particles suspension lining up between the electrodes) i.e. static force which is needed to overwhelmed so that the motion can occur [10]. The force Fc is product of area of electrode and the yield strength of the fluid and does not depend on the electrode plate velocity. The net force F of damping of this ER damper is the sum of two components of force. The main aim of this ER damper is to give large ratio of off-field to on-field damping by force ratios Fy and Fc. Because of this large ratio gives various responses by ER unit with changing voltage.

2.5.2 Valve mode

In this type of mode the ER fluid is pressed between the two electrodes as given in **Figure 5b**. Because of this the ER fluid is exposed to tensile, compression as wells as shear. In the absence of the given electric field if the ER fluid is pressed it behaves like Newtonian fluid. There is a pressure drop AP occurs at flow rate volume Q. This pressure change in between the valve is because of the velocity of the ER fluid. Moreover, during the presence of the electric field, yield stress is generated by the ER fluid which results more pressure drop between the electrodes plates length. The net damping force is summation of two force components of this type of ER

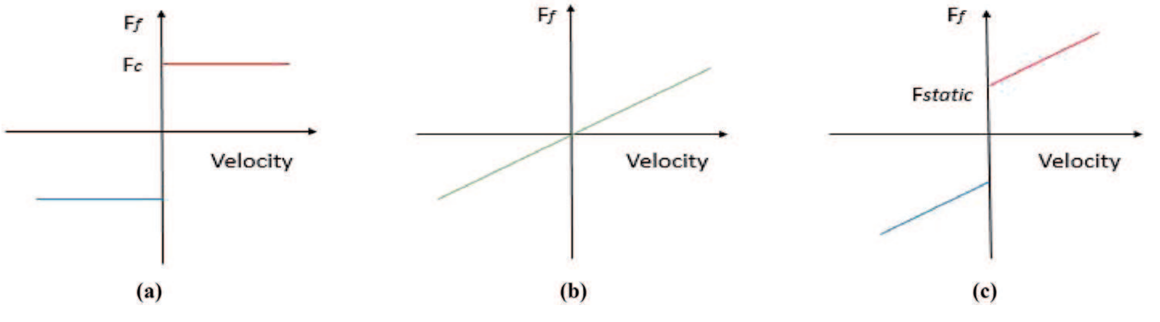

Figure 4.
Actuator friction (a) friction columbic, (b) friction viscous, and (c) total friction.

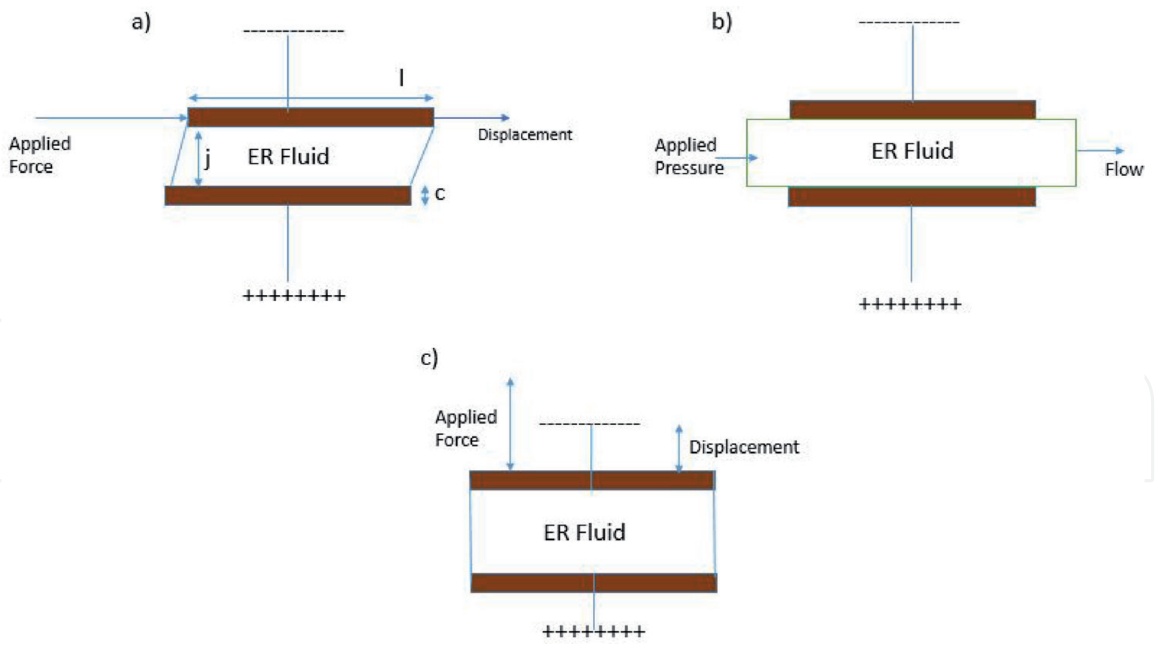

Figure 5.
Modes of operation: (a) shear, (b) valve, and (c) squeeze.

damper. In this type of mode the device effectiveness is the across valves pressure drop with or without the effect of ER [10].

The electrorheological fluids which are totally dependent on the applied electric fields are used in resistive force creation and damping. Examples of applications are active vibration suppression and motion control. L. Wang et al. [4] have presented the uses of ER fluids in microfluidics. Various industries like automobiles industries are demanding modified ER fluids with more efficiency Gurka et.al [6] introduced ER-Fluid RheOil®3.0 which improves the sedimentation and re-dispersing behavior. Brennan et al. [7] studied and distinguished the two classes of the ER dampers, first one acts by shearing the stationary fluid and the second one acts by pumping the ER fluid. The two classes are described in details below.

2.5.3 Squeeze mode

In this mode the gap between the electrodes are changed and the ER fluid is pressed or squeezed by the force acting normally. **Figure 5c** represents the squeezing mode of the ER fluid.

2.5.4 Applications of ER fluid technique in engineering field

ER fluids have wide applicability, economic benefit, social benefit high performance for these advantages these smart fluids will find path in various engineering applications in various technological fields. Without any doubt we can say in the future ER technology is going to rule various applications in engineering technological fields. As soon as this technology is accepted then it will be a revolution in both economy and society. From all these advantages of the ER fluids we can predict that in the near future the ER fluids will be used in various technological fields as given below.

2.5.4.1 Automobile/motor vehicle industry

Scientists and Engineers can develop new kind of parts that can easily fulfill the needs of the motor vehicles using the technology of ER. Like for example ER technology used for cooling engine i.e. speed fan clutch of the motor vehicle, shock absorber, brake having break torque controlled, system for suspensions by damping controlled etc., These components using ER technologies will have less wear and tear, more performance, less cost, prolong life service, controlled easily, easy to produce by microcomputer, fast response, high sensitivity.

2.5.4.2 Hydraulic industry

The valves which are used nowadays for control of pressure and flow rate control can be replaced by ER technology in the future. Because ER technology valves will have no or less movable parts, simple easy structure, low cost, prolong service life, no mechanical processing, minimal tear and wear and electronical control of pressure and rate of flow. For this reasons ER technology will rule the hydraulic industry in the near future.

2.5.4.3 Fluid sealing field

By utilizing the benefits of the ER technology engineers can produce new type of rotational sealing controlled devices for face the challenges of the magnetic fluid sealing and rubber fluid sealing. Because of the pros like good effect of sealing, minimal tear and wear, less magnetic field and prolong life of service.

2.5.4.4 Robotic industry

In robotic industries nowadays for flexible joints are being controlled by hydro-electric control devises instead of ER fluidic joints technology which can perform much better function than the hydraulic-electric control. Engineers are designing and manufacture flexible joints which will have less volume, fast response time, minimal wear as well as tear, nimble, and which can be easily controlled by microcomputers. ER fluids can provide all these advantages over the hydraulic-electric controls.

2.5.4.5 Commercial uses

There are various commercial uses of the ER fluids and many uses are still undiscovered, in automotive industries the ER fluids are used in clutches, seat dampers, shock absorber, engine mount etc. Many other applications of the ER fluids are listed as follows: (a) Fluid flow via thin channel, (b) for friction instruments clutches, (c) servomechanism for impact and vibrator instruments, (d) pick-pick applications, (e) damping isolator, (f) automobile damping, (g) mounts for engine, (h) power transmission in robots, (i) machine tool artificial intelligence, etc. This list is not the final list because still now many uses of the ER fluid in various fields are yet to discover.

3. Characterization of the ER fluid

3.1 Rheological characterization

Rheological characterization is done to identify the change in viscosity of the ER fluid with respect to the shear rate at various electric fields. Garcia et al. [11]

have studied the rheological properties of the ER fluid by using ARES rheometer by using parallel plate diameter 50 mm diameter electrode with 1 mm gap between them. High voltage amplifier was used to supply the DC voltage.

3.2 Dielectric characterization

To study the permittivity and the power factor of the ER fluid the dielectric properties characterization are done. Rejon et al. [12] describes the method of measuring the dielectric properties of the ER fluid. They used guard ring capacitors and high resistor meter. DC high voltages were used for the test.

3.3 Structural characterization

The structural changes of the ER field during and before the DC voltage was studied by Rejon et al. [13]. The studied the microscopic structure of the ER fluid by microscope. They studied the microstructural changes of the ER fluid at different DC applied voltages from 0.5 to 2.5 KV/mm.

4. Conclusion

ER fluids have lots of interesting properties which attracts them in various applications fields among the various important properties of the ER fluid lies fast reaction, precise controllability and easy boundary between the electrical and mechanical input output power. Because of these interesting properties of the ER fluid the ER fluid is used in motion control and will be used in various applications fields in the near years to come. ER fluids characteristics in most advanced way is briefly described below as given in latest reports: (a) When external electric field is given ER effect is seen by change in viscosity of the carrier fluid from liquid to solid as the viscosity of the liquid increases and after removal of the electric field solid to liquid viscosity decreases making the liquid less thick like the initial state, (b) the process in which the ER fluid changes its state from liquid to solid upon application of the electric field must be reversible, i.e., it should return back to its original state (liquid state) as soon as the external electric field is removed. Viscosity change must be less step, (c) upon application of the electric field the transition of the liquid state to the solid state must be very fast, i.e., 5–10 s, (d) and liquid to solid transition must be only possible by electric field only and not by any other means. By all these characteristics of the ER fluid the ER fluid can be connected with the modern technological applications. This technology is one newly type of future challenge as its attractive properties are being used broadly, which can bring a big change in industries. The main component of the ER technology is the ER fluid which should bring in the technological applications like dampers of ER fluids which is a best solution for control of vibrations.

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