Journal of Research and Applications in Mechanical Engineering
ISSN: 2229-2152 (Print); 2697-424x (Online)
(2020) Vol. 8, No. 2, 171-179
DOI: 10.14456/jrame.2020.17

Research Article

A COMPREHENSIVE REVIEW ON THE RHEOLOGICAL CHARACTERISTICS OF PRINTING INK

E. Hosseini*
Department of Mechanical Engineering, Dezful Branch, Islamic Azad University, Dezful, Iran

Received 14 May 2020
Revised 15 June 2020
Accepted 16 June 2020

ABSTRACT:
Generally, printing inks are important due to its application in wide fields including printing of books, journals, and newspapers. Furthermore, printing inks are used to provide information about the produced goods. Understanding the rheology and the potential to evaluate the rheological characteristics is necessary for controlling rheology, and control is essential for the production and handling of many materials especially inks. Hence, the aim of this study is mainly a review based on the rheological properties of printing inks, the effect of viscosity on ink, thixotropic and shear-thinning behaviors of ink as well as considering the past works on screen-printing inks for the production of the solid oxide fuel cell (SOFC) films.

Keywords: *Rheology, Thixotropic behavior, Screen-printing ink, Solid oxide fuel cell, Non-Newtonian properties*

1. INTRODUCTION

Typically, there are different types of printing inks dependent according to the purpose of use, the type of the equipment or press that used in products of the ink, the raw materials and the nature of the surface to be written on i.e. (papers, metallic or non-metallic, cards and plastic), printing press (letterpress, gravure, Lithography, screen saver) [1, 2]. There are many substances used in producing screen printing ink such as alkyd resin, pigment, linseed oil, castor oil, thinner, Toluene, drier. The alkyd resin is the basic component to produce the ink, where it is used as a vehicle and binder to the dye, at the same time it behaves as a thickener substance, where it increases the viscosity of the ink. As for the rest of the substances they help for much adhesion on the wanted surface and exceeds the drying process in lesser time [3]. Rheology is typically the flow behavior science and matter deformation under applied force [4]. Understanding the rheology and the potential to evaluate the rheological characteristics is necessary for controlling the rheology, and control is essential for the production and handling of many materials, i.e. (cosmetics, plastics, paint, inks) [2]. A non-Newtonian fluid is a fluid with characteristics that are different from Newtonian fluids [5]. A non-Newtonian fluid is outlined as one in which the relationship between the shear stress and shear rate is non-linear which is illustrated in Fig. 1 [6].

Many molten polymers and salt solutions are non-Newtonian fluids including substances such as starch suspensions, inks, paint, ketchup, custard, maizena, toothpaste, blood, and shampoo which are found many commonly [7, 8]. Generally, the quality of the screen-printed films is related to many factors such as the settings of the printer, preparation of the substrate, and especially ink rheology [9-11]. They can be controlled throughout the printing process except for the ink rheological characteristics. During the production of solid oxide fuel cell, anode thick films,

* Corresponding author: E. Hosseini
E-mail address: ebrahim.2019.hosseini@gmail.com

electrolyte or cathode can be fabricated by several methods namely screen-printing [12, 13], tape casting [14, 15], gel casting [16-19], sol-gel [20, 21], EVD [22, 23], CVD [24, 25], PVD [26, 27], and magnetron sputtering [28]. Screen-printing is widely operated to generate SOFC components and the production of optimized screen-printing inks is highly important to produce high-quality films with improved performance.

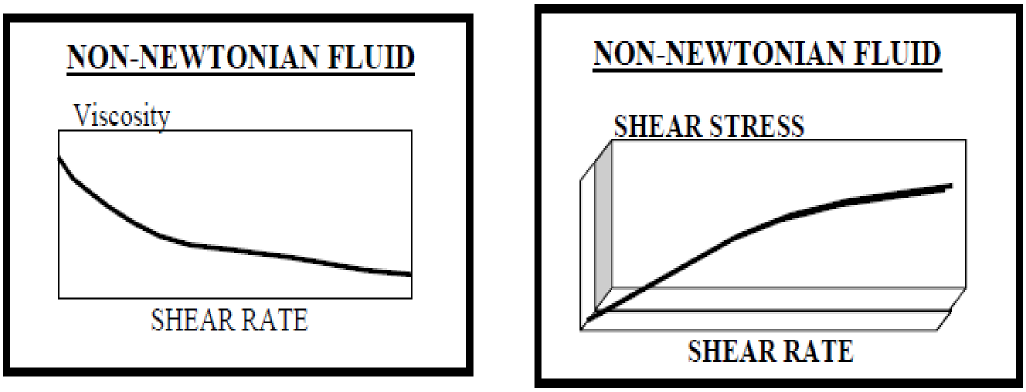


Fig. 1. Relationship between shear rate and viscosity [6].

The current study, which is basically a brief overview of ink rheology, is trying to explain the rheological behavior of ink and discuss the effect of viscosity, shear-thinning, and thixotropic behavior of printing ink. Moreover, a special attempt is done to consider and review the past works on the fabrication of solid oxide fuel cell (SOFC) films using screen-printing ink.

2. PRINTING INK

Printing inks are used in thin films for different substrates such as paper, metal sheets, plastic films, glass, and textiles [29]. It is generally conceded that there are four classes of printing inks, which differ remarkably in the method of application and physical appearance. They are letterpress and lithographic inks, which are commonly called oil inks or paste inks, usually of a pasty consistency, and flexographic, rotogravure, screen saver inks which are called solvent or liquid inks. Four properties of inks are of cardinal importance-drying, printability which is largely a function of the ink rheology, and color. There are four main printing processes: relief or letterpress, intaglio or gravure, planographic or lithography, and stencil or screen printing [6]. Screen printing inks often known as Silk-Screen inks in the past which are dispersions of pigments in vehicles [30]. Silk-Screen inks are used for greeting cards, board, paper posters, ceramics, and plastic [31].

3. RHEOLOGICAL PROPERTIES OF PRINTING INK

Generally, in the fabrication of optimal screen printed films, the quality of the screen-printed films is related to many factors such as the settings of the printer, preparation of the substrate, and especially ink rheology [11, 32]. They can be controlled throughout the printing process except for the ink rheological characteristics. The rheological characteristic can be measured with the specification of the steady-state and dynamic properties of the inks which have a great impact on the film properties. Viscosity is defined as the resistance of the liquid to flow [33]. When fluid begins to flow under the action of a force, shearing stress occurred everywhere in that fluid which tends to oppose the motion [34]. Typically, high viscosity appears on screen [6]. The viscosity of the ink can be characterized using cone and plate rheometer or disk, to capture a shear-viscosity relationship [35]. Viscosity is significant for ink quality: ink is made up of color pigment, resin, and solvent. Evaporation of the solvent in printing operations increases percent solids, causing changes in color and solid concentration this leads to increasing viscosity [36].

The ratio of shear stress to shear rate is viscosity which can be written as:

$$Viscosity = \frac{Shear\ stress}{Shear\ rate} \tag{1}$$

Also, viscosity is more easily evaluated than some other properties which make it a precious tool to characterize the material. The material composition is a determining factor of its viscosity, when this composition is varied, a change in viscosity is very likely. For instance; the viscosity has decreased by adding a solvent to printing inks [37]. Pseudo-plastic (shear-thinning) fluid will indicate a reduction in viscosity with an increase in shear rate, as illustrated in Fig. 2, probably the most common of the non-Newtonian fluid, pseudo-plastic includes inks, paints, etc. [38]. When the shear rate is increased, almost all of the non-Newtonian fluids undergo a simple increase or decrease in viscosity. In Pseudo-plastic (shear thinning) fluid, the viscosity decreases as the shear rate increases, and the opposite effect is known as dilatant (shear-thickening).

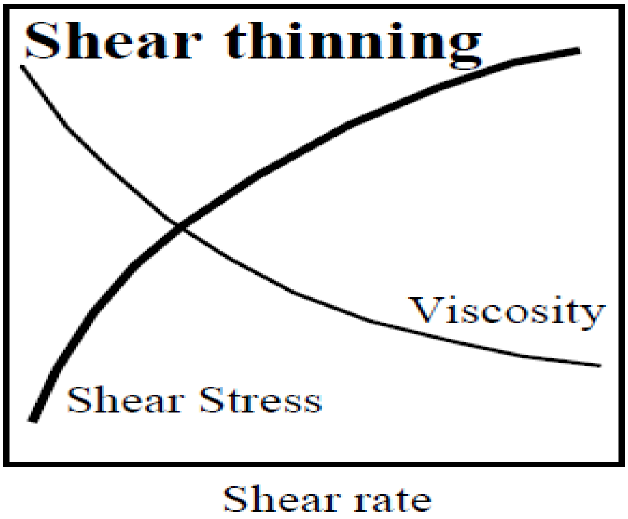


Fig. 2. The flow and viscosity curves of shear-thinning fluid [6].

The power law's which is an empirical functional relation widely used to describe fluids of this type. This relation, which was original, presented by de waele (1923) and Ostwald (1925) [6], as shown in Equation (2).

$$\tau = K \left(\frac{\partial u}{\partial y}\right)^n \tag{2}$$

where n is referred to the power-law index. If $n < 1$, the material is called pseudo-plastic, if $n > 1$, then the material is called dilatant and, if $n = 1$ then the material is Newtonian [39]. The power law is a good criterion to describe the Rheological characteristics of printing ink. This type of ink is non-Newtonian. The shear stress is variable with shear rate, and this behavior indicates that the ink has pseudo-plastic properties. If $n < 1$ for pseudo-plastic, the viscosity function decreases as the shear rate increases. The ink is non-Newtonian because the relation between shear rate and shear stress is not linear demonstrating that ink has pseudo-plastic properties [6]. Generally, rheological analysis is conducted using steady-state, oscillation, yield stress, and creep recovery examinations [9, 40]. The yield stress measurement and steady-state test are applied to consider the thixotropic behavior of inks [41]. The oscillation examination evaluates the viscoelastic properties, while the creep-recovery test is carried out to investigate the slump properties of inks [41, 42]. Viscosity is a steady-state rheology property of the ink. In general, this property enhances while the solid and/or binder content increases [43, 44]. It was stated that inks have a viscosity in the range of 4-12 Pa.s. For yttria-stabilized zirconia (YSZ) inks, it is measured at the shear rate of 100 s^{-1}. This is typically adequate for screen-printing applications [43]. Also, Sanson et al. [45] reported a similar viscosity range for CGO electrolyte inks. In the study of Somalu et al. [46, 47], the acceptable viscosity ranges specified 15-45 Pa.s at a similar shear rate of 100 s^{-1}. The differences in the viscosity ranges showed that the steady-state rheological properties are not adequate to obtain the optimized screen-printing inks. Therefore, additional measurements may help specify the most optimum inks for screen-printing applications. Thixotropy is one of the important rheological properties of printing ink which depicts the change of viscosity with the time, therefore, considering the relation between shear rate and shear stress with time is significant. Figure 3 has two curves up and down curves. The up curve illustrates that the viscosity decreases gradually with the increment of the shear rate. The down curve shows that the shear rate decreases again to zero which means viscosity decreases and begins to increase, which leads to a decrease in the shear stress. Figure 3 indicates that the ink behaves thixotropic as evidenced by previous studies for other ink types [46]. This figure illustrates the variation of shear stress with a shear rate of two curves at alkyd resin concentration (28 wt%) and different times [6].

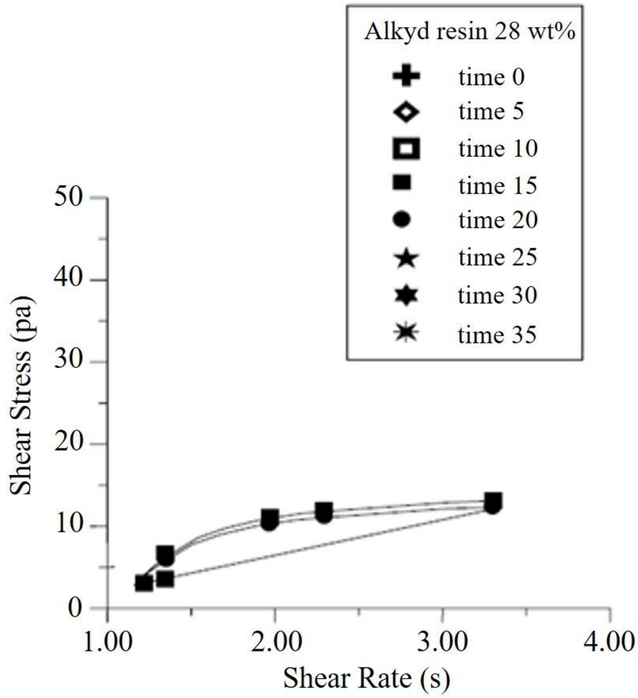


Fig. 3. Shear stress (Pa) versus shear rate (sec^{-1}) [6].

The ink dispersion can be determined by evaluating the degree of ink thixotropy. Also, thixotropic behavior can be measured by the application of shear jump test [32] which is commonly significant for screen-printing [32, 45]. Somalu et al. [9, 41] concluded that the NiO/ScSZ anode inks without binder and inks with lower solids content showed poor thixotropic behavior. These inks were assessed as not appropriate for screen-printing. The poor thixotropic properties of inks may generate cracked films after sintering which is observed in water-based CGO inks [45]. Furthermore, Phair et al. [32] considered the thixotropic behavior of YSZ inks having several binder contents with the application of shear jump test.

4. Fabrication of SOFC Films

Fabrication of SOFC components through an easy and low-cost method is important to decrease the entire manufacturing cost of solid oxide fuel cells. Screen-printing is economical, simple, and flexible and it is an extensive used method for the fabrication of SOFC films [10, 13]. Therefore, screen-printing is carried out to make SOFC components which have a thickness of 10-100 μm. In order to produce high-quality films, the manufacturing of optimized screen-printing ink is extremely significant. Understanding the ink rheological characteristics is related to the effects of some parameters such as binder, solvent, solid, and dispersant which can be optimized by evaluating the ink rheological properties including thixotropy, viscoelasticity, viscosity, and yield stress. Consequently, consideration of the relationship between the ink rheology and its composition may improve the performance of the resultant screen-printed films [47]. As mentioned before, in the fabrication of SOFC, anode thick films, electrolyte or cathode can be fabricated by several methods namely screen-printing [12, 13], tape casting [14, 15], gel casting [16-19], sol-gel [20, 21], EVD [22, 23], CVD [24, 25], PVD [26, 27], and magnetron sputtering [28]. There are three steps in the screen-printing process which demonstrated that ink rheology plays a major role in the manufacturing of high-quality films with the enhanced performance [48, 49]. Moreover, the screen-printing method has been widely used in the production of solar cell films [50], oxides [51], and photoconductors [52]. Generally, screen-printing is applied to generate thick films and used in SOFC such as YSZ [11], LSCF [53], and NiO/YSZ [54]. Somalu et al. considered the rheological properties of Ni/ScSZ inks in the production of solid oxide fuel cells [55]. They extend their previous works [9, 41] and analyzed the correlation between ink rheology, and film properties namely electrochemical performance, the quality of printed films, and electrical performance. Also, Somalu et al. examined the effect of the binder content on the ink rheological characteristics [56-58]. They used SEM images of printed films to consider the effect of binder content on the mechanical strength, and electrochemical performance of the anode films and finally correlate them to the inks rheological properties [55]. Somalu et al. [59] considered the effects of binder content on the rheological characteristics of NiO/ScSZ ink. The steady-state examination was carried out by linearly increasing the shear rate from 0.1 to 100 S^{-1}. The thixotropic properties of inks increase as the binder content rises which is shown in Fig. 4, but ink without binder demonstrated shear-thinning behavior which is not appropriate for screen printing. From the point of both ink rheology and performance, they found that ink with 3 wt % binder was specified to be optimum. It should be noted that wt % refers to the percentage of binder content of cermet powder.

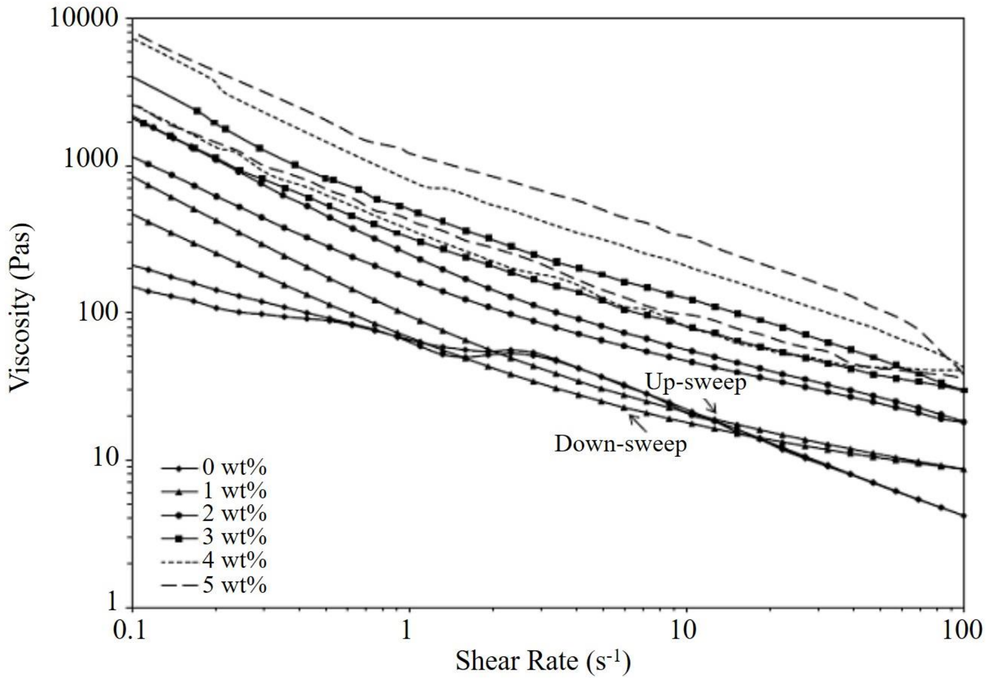
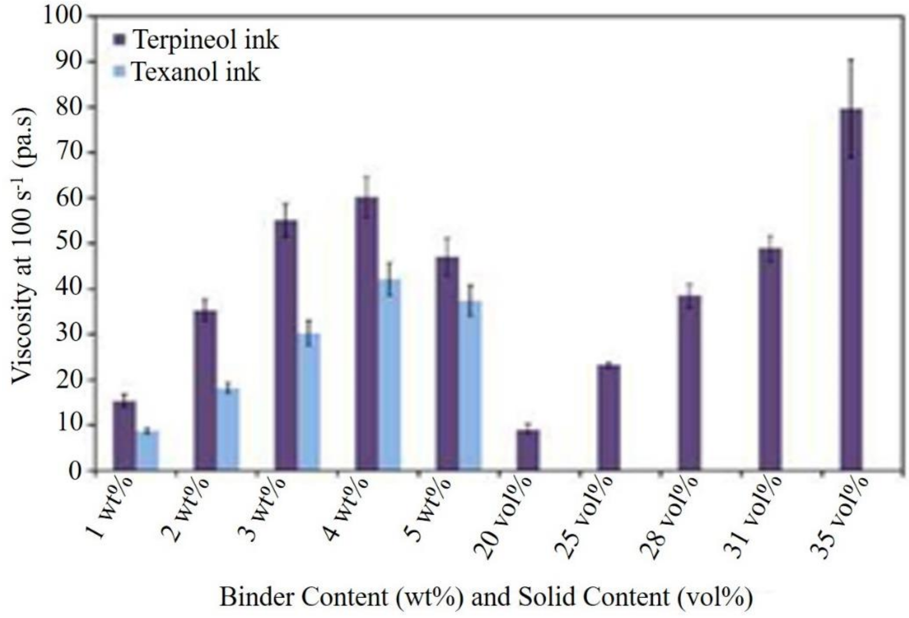
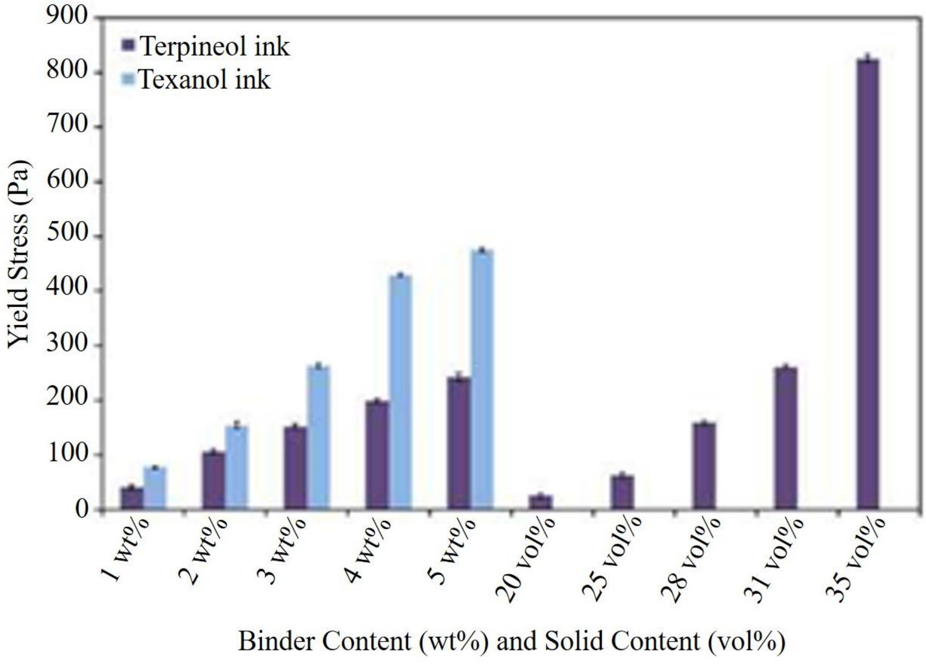


Fig. 4. Viscosity as a function of ink shear rate [59].

Also, in the study of Somalu et al. [60], the effect of ink rheology on the properties of screen-printed Ni/ScSZ anode has been investigated. Figure 5 shows the viscosity and yield stress results for terpineol and texanol inks as a function of binder and solids content. In this figure, the yield stress and viscosity enhance with the increase of binder and solids content due to the increment of particle association. They found that inks represent adequate viscosity and thixotropy with acceptable tackiness for screen-printing applications [60].



(a)



(b)

Fig. 5. (a) Viscosity and (b) Yield stress of NiO/ScSZ inks [60].

5. Conclusion

In the present review, the rheological properties of printing inks, the effect of viscosity for ink, shear-thinning, and thixotropic behaviors of ink were investigated. Moreover, the past works on screen-printing inks for the production of SOFC were considered. As referred previously in the body of the paper, when the shear rate is increased, almost all of the non-Newtonian fluids undergo a simple increase or decrease in viscosity. If the viscosity decreases as the shear rate increases, the material is said to be pseudo-plastic (shear thinning). According to Power-law, the printing ink is non-Newtonian. If $n < 1$ for pseudo-plastic, the viscosity function decreases as the shear rate increases. The shear stress is variable with the shear rate, and this behavior indicates that the ink has pseudo-plastic properties. Thixotropy is one of the important rheological properties of printing ink which represents the change of viscosity with the time and it is stated by previous studies that printing ink behaves as thixotropic. Fabrication of SOFC components through the screen-printing technique is important to decrease the entire manufacturing cost of solid oxide fuel cells. Also, in order to produce high-quality films, the manufacturing of optimized screen-printing ink is extremely significant. Consequently, consideration of the relationship between the ink rheology and its composition may improve the properties and performance of the resultant screen-printed films.

REFERENCES

[1] Bhow, N.R., and Payne, H.F. Styrene copolymers in alkyd resins, Industrial & Engineering Chemistry, Vol. 42(4), 1950, pp. 700-703.

[2] Schoff, C.K. and Kamarchik, P. Rheological measurements, Kirk-Othmer Encyclopedia of Chemical Technology, 1997, Wiley, New York.

[3] Batchelor, G.K. An introduction to fluid dynamics, 1967, Cambridge University Press, Cambridge.

[4] Eirich, F. Rheology V2: Theory and applications, 2012, Academic Press, United States.

[5] Yang, L. and Du, K. A comprehensive review on the natural, forced, and mixed convection of Non-Newtonian fluids (nanofluids) inside different cavities, Journal of Thermal Analysis and Calorimetry, Vol. 140(1), 2020, pp. 2033-2054.

[6] Al-Hamde, M. Rheology of screen printing ink, Dissertations, 2004, Al-Nahrain University, Iraq.

[7] Da silva, J.L. and Rao, M.A. Rheological behavior of food gels, Rheology of fluid and semisolid foods, 2007, Springer, United States.

[8] Khan, Z.H., Khan, W.A. and Hamid, M. Non-Newtonian fluid flow around a Y-shaped fin embedded in a square cavity, Journal of Thermal Analysis and Calorimetry, 2020, pp.1-13.

[9] Somalu, M. R. and Brandon, N.P. Rheological studies of nickel/scandia-stabilized-zirconia screen printing inks for solid oxide fuel cell anode fabrication, Journal of the American Ceramic Society, Vol. 95(4), 2012, pp. 1220-1228.

[10] Zhou, X., Deng, J., Fang, C., Yu, R., Lei, W., He, X., et al. Preparation and characterization of lysozyme@ carbon nanotubes/waterborne polyurethane composite and the potential application in printing inks, Progress in Organic Coatings, Vol. 142, 2020, 105600.

[11] Von Dollen, P. and Barnett, S. A study of screen printed Yttria-Stabilized zirconia layers for solid oxide fuel cells, Journal of the American Ceramic Society, Vol. 88(12), 2005, pp. 3361-3368.

[12] Jou, S. and Wu, T. Thin porous Ni–YSZ films as anodes for a solid oxide fuel cell, Journal of Physics and Chemistry of Solids, Vol. 69(11), 2008, pp. 2804-2812.

[13] Hildenbrand, N., Nammensma, P., Blank, D.H., Bouwmeester, H.J. and Boukamp, B.A. Influence of configuration and microstructure on performance of La2NiO4+ δ intermediate-temperature solid oxide fuel cells cathodes, Journal of power sources, Vol. 238(1), 2013, pp. 442-453.

[14] Fu, C., Chan, S.H., Liu, Q., Ge, X. and Pasciak, G. Fabrication and evaluation of Ni-GDC composite anode prepared by aqueous-based tape casting method for low-temperature solid oxide fuel cell, International Journal of Hydrogen Energy, Vol. 35(1), 2010, pp. 301-307.

[15] Maric, R., Neagu, R., Zhang-Steenwinkel, Y., Van Berkel, F.P. and Rietveld, B. Reactive spray deposition technology one-step deposition technique for solid oxide fuel cell barrier layers, Journal of Power Sources, Vol. 195(24), 2010, pp. 8198-8201.

[16] Durango-Petro, J., Usuba, J., Valle, H., Abarzua, G., Flies, H., Udayabhaskar, R., et al. Ascendable method for the fabrication of micro-tubular solid oxide fuel cells by ram-extrusion technique, Ceramics International, Vol. 46(3), 2020, pp. 2602-2611.

[17] Li, G. and Ren., R. Preparation of YSZ-TZP solid electrolytes by gel-casting technology, Journal of Environmental Sciences, Vol. 23(2), 2011, pp. S170-S172.

[18] Liu, Y., Tang, Y., Ding, J. and Liu, J. Electrochemical performance of cone-shaped anode-supported segmented-in-series SOFCs fabricated by gel-casting technique, International Journal of Hydrogen Energy, Vol. 37(1), 2012, pp. 921-925.

[19] Navarro, M.E., Capdevila, X.G., Morales, M., Roa, J.J. and Segarra, M. Manufacturing of anode-supported tubular solid oxide fuel cells by a new shaping technique using aqueous gel-casting, Journal of Power Sources, Vol. 200(1), 2012, pp. 45-52.

[20] Han, F., Van Gestel, T., Mücke, R. and Buchkremer, H.P. Development of nano-structured YSZ electrolyte layers for SOFC application via sol-gel route, Ceramic Transaction, Vol. 210(1), 2010, pp.165-171.

[21] Macedo, D.A., Figueiredo, F.M., Paskocimas, C.A., Martinelli, A.E., Nascimento, R.M. and Marques, F.M. Ni–CGO cermet anodes from nanocomposite powders: Microstructural and electrochemical assessment, Ceramics International, Vol. 40(8), 2014, pp. 13105-13113.
[22] Erilin, I.S., Agarkov, D.A., Burmistrov, I.N., Pukha, V.E., Yalovenko, D.V., Lyskov, N.V., et al. Aerosol deposition of thin-film solid electrolyte membranes for anode-supported solid oxide fuel cells, Materials Letters, Vol. 266, 2020, 127439.
[23] Haldane, M. and Etsell. T. Fabrication of composite SOFC anodes using polarized electrochemical vapor deposition, Fuel Cells Bulletin, Vol. 2005(7), 2005, pp. 12-16.
[24] Ferlauto, A.S., De Florio, D.Z., Fonseca, F.C., Esposito, V., Muccillo, R., Traversa, E., et al. Chemical vapor deposition of multi-walled carbon nanotubes from nickel/yttria-stabilized zirconia catalysts, Applied Physics A, Vol. 84(3), 2006, pp. 271-276.
[25] Liu, Y., Zha, S. and Liu, M. Novel nanostructured electrodes for solid oxide fuel cells fabricated by combustion chemical vapor deposition (CVD), Advanced Materials, Vol. 16(3), 2004, pp. 256-260.
[26] Uhlenbruck, S., Jordan, N., Serra, J.M., Buchkremer, H.P. and Stöver, D. Application of electrolyte layers for solid oxide fuel cells by electron beam evaporation, Solid State Ionics, Vol. 181(8-10), 2010, pp. 447-452.
[27] Meng, B., He, X. D., Sun, Y. and Li, M.W. Preparation of porous Ni–YSZ coatings by EB–PVD, Materials Science and Technology, Vol. 25(1), 2009, pp. 117-120.
[28] Nédélec, R., Uhlenbruck, S., Sebold, D., Haanappel, V.A., Buchkremer, H.P. and Stöver, D. Dense yttria-stabilised zirconia electrolyte layers for SOFC by reactive magnetron sputtering, Journal of Power Sources, Vol. 205(1), 2012, pp. 157-163.
[29] Ferguson, J. and Kemblowski, Z. Applied fluid rheology, 1991, Springer, United States.
[30] Bassemir, R.W., Bean, A., Wasilewski, O., Kline, D., Hillis, W., Su, C., et al. Inks, Kirk-Othmer Encyclopedia of Chemical Technology, 2004, Wiley, New York.
[31] Sherman, P. Industrial rheology with particular reference to foods, pharmaceuticals, and cosmetics, 1970, Academic Press, New York.
[32] Phair, J.W., Lundberg, M. and Kaiser, A. Leveling and thixotropic characteristics of concentrated zirconia inks for screen-printing, Rheologica acta, Vol. 48(2), 2009, pp. 121-133.
[33] Patton, T.C. Paint flow and pigment dispersion: a rheological approach to coating and ink technology, 1979, Wiley, New York.
[34] Harris, J. Rheology and non-Newtonian flow, 1977, Longman Publishing, United Kingdom.
[35] Schowalter, W.R. Mechanics of non-Newtonian fluids, 1978, Pergamon press, Oxford.
[36] Rune, E. Measuring instrument of the recording type, U.S. Patent No. 2566443, 1951, United States.
[37] Gupta, R.K. Polymer and composite rheology, 2000, CRC Press, United States.
[38] Van Wazer, J.R. Viscosity and flow measurement: a laboratory handbook of rheology, 1963, Interscience Publishers, United States.
[39] Wilkinson, W.L. Non-Newtonian fluids: fluid mechanics, mixing and heat transfer, 1960, Pergamon Press, London.
[40] Tseng, W.J. and Lin, K. Rheology and colloidal structure of aqueous TiO_2 nanoparticle suspensions, Materials science and engineering, Vol. 355(1-2), 2003, pp. 186-192.
[41] Somalu, M.R., Yufit, V. and Brandon, N.P. The effect of solids loading on the screen-printing and properties of nickel/scandia-stabilized-zirconia anodes for solid oxide fuel cells, International Journal of Hydrogen Energy, Vol. 38(22), 2013, pp. 9500-9510.
[42] Mallik, S., Schmidt, M., Bauer, R. and Ekere, N.N. Influence of solder paste components on rheological behaviour, paper presented in the Electronics System-Integration Technology Conference, 2008, Greenwich, United Kingdom.
[43] Ried, P., Lorenz, C., Brönstrup, A., Graule, T., Menzler, N.H., Sitte, W., et al. Processing of YSZ screen printing pastes and the characterization of the electrolyte layers for anode supported SOFC, Journal of the European Ceramic Society, Vol. 28(9), 2008, pp. 1801-1808.
[44] Marani, D., Gadea, C., Hjelm, J., Hjalmarsson, P., Wandel, M. and Kiebach, R. Influence of hydroxyl content of binders on rheological properties of cerium–gadolinium oxide (CGO) screen printing inks, Journal of the European Ceramic Society, Vol. 35(5), 2015, pp. 1495-1504.
[45] Sanson, A., Roncari, E., Boldrini, S., Mangifesta, P. and Doubova, L. Eco-friendly screen-printing inks of gadolinia doped ceria, Journal of Fuel Cell Science and Technology, Vol. 7(5), 2010, 051013.
[46] Green, D.W. and Southard, M.Z. Perry's chemical engineers' handbook, 2018, McGraw Hill, United States.
[47] Somalu, M.R., Muchtar, A., Daud, W.R.W. and Brandon, N.P. Screen-printing inks for the fabrication of solid oxide fuel cell films: a review, Renewable and Sustainable Energy Reviews, Vol. 75(1), 2017, pp. 426-439.

[48] Trease, R.E. and Dietz, R.L. Rheology of pastes in thick-film printing, Solid state technology, Vol. 15(1), 1972, pp. 39-51.
[49] Thibert, S., Jourdan, J., Bechevet, B., Chaussy, D., Reverdy-Bruas, N. and Beneventi, D. Influence of silver paste rheology and screen parameters on the front side metallization of silicon solar cell, Materials science in semiconductor processing, Vol. 27(1), 2014, pp. 790-799.
[50] Li, H., Xie, Z., Zhang, Y. and Wang, J. The effects of ethyl cellulose on PV performance of DSSC made of nanostructured ZnO pastes, Thin Solid Films, Vol. 518(24), 2010, pp. 68-71.
[51] Ismail, B., Abaab, M. and Rezig, B. Structural and electrical properties of ZnO films prepared by screen printing technique, Thin Solid Films, Vol. 383(1), 2001, pp. 92-94.
[52] Hasan, K., Nur, O. and Willander, M. Screen printed ZnO ultraviolet photoconductive sensor on pencil drawn circuitry over paper, Applied Physics Letters, Vol. 100(21), 2012, 211104.
[53] Burnat D., Ried P., Holtappels P., Heel A., Graule T. and Kata D. The rheology of stabilized lanthanum strontium cobaltite ferrite nanopowders in organic medium applicable as screen printed SOFC cathode layers, Fuel Cells, Vol. 10(1), 2010, 156e65.
[54] Rotureau, D., Viricelle, J.P., Pijolat, C., Caillol, N. and Pijolat, M. Development of a planar SOFC device using screen-printing technology, Journal of the European Ceramic Society, Vol. 25(12), 2005, pp. 2633-2636.
[55] Somalu, M.R., Yufit, V., Shapiro, I.P., Xiao, P. and Brandon, N.P. The impact of ink rheology on the properties of screen-printed solid oxide fuel cell anodes, International Journal of Hydrogen Energy, Vol. 38(16), 2013, pp. 6789-6801.
[56] Somalu, M.R., Yufit, V., Cumming, D., Lorente, E. and Brandon, N.P. Fabrication and characterization of Ni/ScSZ cermet anodes for IT-SOFCs, International Journal of Hydrogen Energy, Vol. 36(9), 2011, pp. 5557-5566.
[57] Eguchi, K., Tanaka, K., Matsui, T. and Kikuchi, R. Reforming activity and carbon deposition on cermet catalysts for fuel electrodes of solid oxide fuel cells, Catalysis Today, Vol. 146(1), 2009, pp. 154-159.
[58] Ke, K., Gunji, A., Mori, H., Tsuchida, S., Takahashi, H., Ukai, K., et al. Effect of oxide on carbon deposition behavior of CH 4 fuel on Ni/ScSZ cermet anode in high temperature SOFCs, Solid State Ionics, Vol. 177(5), 2006, pp. 541-547.
[59] Somalu, M.R., Brandon, N.P. and Yufit, V. A study of the rheological properties of NiO/ScSZ screen-printing inks and their application to SOFC anodes, ECS Transactions, Vol. 35(1), 2011, pp. 1483-1500.
[60] Somalu, M.R., Muchtar, A. and Brandon N.P. Understanding the Rheology of screen-printing inks for the fabrication of SOFC thick films, ECS Transactions, Vol. 68(1), 2015, pp. 1323-1331.