POWER CONSUMPTION OF VISCOELASTIC FLUIDS OUT Of UNAERETED MECANICALLY AGITED VESSEL BY A TURBINE RUSHTON

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Summary:

Most of the elastic fluids are pseudoplastic and this causes difficulties of clear interpretation of the experimental results in which the effects due to inertia, elasticity and the variation of viscosity affect the power consumption, hydrodynamic and the phenomena of heat or mass transfer. In the literature, Nagata is one of the rare authors to propose a correlation of power consumption for Newtonian fluid agitated by two-bladed impeller from laminar to turbulent flow. For the Newtonian fluids agitated by a Rushton turbine, we propose the equation of the number of power consumption Np in relation with the Reynolds number Re :

$$Npn = Kp/Re + (An + NptnRe)/(Cn + Re)$$

$$\text{with } kp = 75;\ An = 1018;\ Cn = 431;\ Nptn = 5{,}3$$

kp and Npt are respectively the constants of power consumption in streamline and turbulent flow , An and Cn are coefficients.

In viscoelastic area characterized by the number of elasticity Elo ($Elo = t\omega o/\eta\rho d^2$) taking into account the properties of the fluid (characteristic time $t\omega o$, viscosity η, density ρ) and the diameter d of the agitator, a correlation of power consumption was proposed. This equation is parameterized by the number of.elasticity Elo and the generalized Reynolds number generalized Reg ($Reg = \rho N^{2-n}d^2/kkmo^{n-1}$) according to the concept of Metzner-Otto:

$$Np = Kp/Reg + (A + NptReg)/(C + Reg)$$

with kp = 75; $A = 1018/(1 + 2{,}8\ Elo^{0,5})$; $C = 431/(1 + 0{,}389 Elo^{0,5})$; $Npt = 5{,}3 - 1{,}Elo^{0,075}$ (Npt = 5,3 for the liquids of category I)

It reveals two categories of viscoelastic fluids: those of the first category the PEF I (pseudoplastic and elastic fluids I), marked by a strong viscosity and a weak natural time reduce the power to the beginning of the intermediairy regim, while those of the second category, the PEF II (pseudoplastic and elastic fluid II), characterized by a strong viscosity and a high natural time, reduce considerably the power towards the end of the intermediairy regim.

Key words: viscoelastic fluid, power consumption, Rushton turbine, number of elasticity.

I Introduction

The power consumption in mechanically agitated vessel is represented in adimensionall form by Np ($Np = P/\rho N^3 d^5$). It depends on the rheological properties, the hydrodynamic flow, geometrical dimensions of the tank and the mobile. In the case of the viscoelastic fluids agitated by a Rushton turbine, the primary, secondary or tertiary flows can be disturbed by rheology. The complex effects of the elasticity and the pseudoplasticity on the hydrodynamic of the elastic fluids results in is by :

- an intermediary flow between that of the purely viscous fluids and that of very elastic Boger's fluids [2,3,4,5]
- a reversed flow with effect Weissenberg [6,7]
- a similar flow to those of the purely viscous fluids [8,9]

The power consumption of the viscoelastic fluids, in tank agitated by impellers turbines, has been very little discussed in the literature. The comparison of the results of the authors is made difficult because of the uniformity lack of the adimensional numbers characterizing the elastic properties of the fluids or the value of the constant of Metzner-Otto (value 11 is used). Thus, certain authors [6,7,10,11] use the number of Weissenberg We, or numbers it of Deborah (De) [12,13]. These numbers are defined like the report/ratio of characteristic time of the fluid to that of the process (speed consumption). Characteristic time is a natural time, strongly correlated at a viscosimetric time, being able to be calculated at : - an arbitrary share rate of reference [5,12], no one share rate [5,14] or share rate of Metzner-Otto [4,8,9,10,11,15] - an arbitrary shear stress [5,12] . Other authors [8,9,15, 16] prefer the number of elasticity El, definite like the ratio of the elastic forces on the viscous forces El = Wi (or De)/Re). It is rare also to find in the literature to find mathematical models predicting the power consumption of the streamline flow until to the turbulent flow. The only one model to predict power consumption is that of Nagata [17] proposed for the Newtonian fluids agitated by two-bladed impeller :

$$Npn = Kp/Re + B(1000 + 3{,}2Re^{0,66})/(1000 + 2{,}6Re0{,}66) \qquad [\ I\ ]$$

For the pure and pseudoplastic fluids or the pseudoplastic and elastic fluids, the majority of the authors are satisfied of the simple analysis with l.allure of the curve of power consumption. In intermediate mode flow , the majority of the authors [4,7,12,18] note a reduction of power being able to reach 50% compared to the Newtonian reference. In streamline flow certain authors [11,12,18] observe an increase in power per report/ratio the Newtonian curve. This shift can be estimated like an over-estimate of the constant of Metzner-Otto. For the very elastic fluids known as Boger fluids, used to eliminate the disturbing effect due to the pseudoplaticity, paradoxically more incoherency is noted in the results published. Certain authors [8,9,15] observe an augmentation of the power consumption in streamline flow others [5,6,10] note a reduction. Moreover, at the intermediate mode flow beginning, an inconsistency is also noted : Ozcan [8] observe an augmentation of power consumption , while Allsford [10] and Oliver & collar [6] evoke a reduction compared to the Newtonian reference. The complexity and apparent incoherency of the effects observed according to authors' could be explained by the action of the elastic component on the hydrodynamic flow of the of the impellers, action which changes according to the elasticity degree and the Reynolds number [6]. In this study, the elastic component of viscoelastic fluid quantified by the number of elasticity Elo ($Elo = t\omega o \eta o/\rho d^2$), into which is introduced the time of Truesdel $t\omega o$ ($t\omega o = \lim [\, \eta''/\omega\eta' \,]\ \omega \to 0$), is selected to estimate the power consumption in an unaereted mechanically agitated tank by a Rushton turbine.

II Experiment:

The experimental device of measurement of power, is two standard Plexiglass tanks of diameter D equal 0,30m and 0,455 m. The impellers used are Rushton turbines of diameter d such as d/D = 1/3 and 1/2. For various speeds of the agitators, the power is measured with torquemeter interdependent of the engine of agitator. The studied fluids are high polymer solutions of guar (IRANEX), of CMC (HERCULES) and of polyacrylamid PAA (HERCULES). Their rheological parameters were measured with a rheometer Suck V10 and a rheomat 30 (Co. Rheometrics) at 20°C. The parameters of the rheological model of Oswald k and n are calculated with share rate ranging between 0 and 100 s^{-1}. The Truesdel natural time ($t\omega o = \lim [\, \eta''/\omega\eta' \,]\ \omega \to 0$) was measurement with a rheometer Suck V10 in oscillatory mode for share rate ranging between 0,02 and $3s^{-1}$. The viscosity of the Newtonian plateau ηo is calculated with rheological models with 3 or 4 parameters (Cross, Carreau-Yashuda).The Metzner-Otto constant is measured for all the fluids used in streamline flow by the method of Reiger and Novak [19]. All the rheological parameters of the fluids are gathered in table I.

Fluides		Rheological parameters of Oswald's model at 20°C		kmo	d/D= 0,33	d/D = 0,50
	ηo	n	k		Elo	Elo
Glycerin		1	-		0	0
Guar 1%	3,03	0,42	4,02	12		
Guar 1,5%	20,6	0,32	13,58	11,8	5,57	2,47
CMC7H4C 1%	5,4	0,41	7,24	9,55	2,69	1,19
CMC7H4C 1,5%	43,2	0,362	22	7,83	44,1	19,6
PAA 0,1%	12,2	0,32	0,97	11,8	28,7	12,9
PAA 0,2%	33	0,26	1,18	11,8	80,3	36,2
PAA 0,3%	42,7	0,29	3,2	10,89	108,8	499,0
PAA 0,5%	79,2	0,184	8,2	10,3	240,9	107,9
PAA 0,75%	174	0,164	14,9	10,2	488,2	216,9
PAA 0,95%	381	0,158	16,9	9,6	1004	446,1
Boger 50 ppm	0.8	1	-	-		
Boger 100 ppm	1.04	1	-	-		

Tableau I : rheological properties of the fluids used

III Results and discussion

The number of Deborah ($De = Nt\omega o$) in which is introduced natural time of Truesdel is retained, because it has advantage to not impose the same reference of gradient of time characteristic as that of the process. Among possible times of processes (time of pumping, time of circulation) the speed of the impeller is selected because it is most accessible in complex fluid aera. The elasticity degree of each fluid out of mechanically agitated tank is quantified by Elo to estimate the power consumption and the thermal coefficient of transfer. In Newtonian aerea (figure1), with regard to the power consumption, we propose the equation:

$$Np = Kp/Re + (An + NptnRe)/(Cn + Re) \qquad [\ II\ ]$$

$$\text{with } kp = 75;\ An = 1018;\ Cn = 431;\ Nptn = 5{,}3$$

The constants of power in streamline and turbulent flows , respectively kp and Nptn are in conformity with the results published by Rusthon [19].

Figure 1: Power consumption of a fluid Newtonian

For the elastic and pseudoplastic fluids, the modeling of the experimental results of measurements of power (figures 2,3,4,5) led to the equation:

$$Np = Kp/Reg + (A + Npt\,Reg)/(C + Reg) \quad [\ II\ ]$$

With $kp = 75$; $A = 1018/(1 + 2{,}8\,Elo^{0{,}5})$; $C = 431/(1 + 0{,}389\,Elo^{0{,}5})$;

$Nptn = 5{,}3 - 1{,}5\,Elo^{0{,}075}$ ($Npt = 5{,}3$ for the liquids of category I)

In the equation [III], Npt the value limits number of power in turbulent flow which is not reached for all the studied fluids. The coefficients A, C and Npt are a function of the elasticity degree of the fluid Elo. They are obtained by slip of the curves of power consumption of the viscoelastic fluids on that of the Newtonian reference.

Figure 2: Power consumption of the Guar solutions Vessel II D = 0,445m; d/D = 0,50

Figure 3: Power consumption of the Guar solution – Vessel II D = 0,445m; d/D = 0,33

Figure 4: Power consumption of the CMC solutions – Vessel II D = 0.445m; d/D = 0.33

Figure 5: Power consumption of the CMC solution - Vessel II D = 0.445m; d/D = 0.5

Figure 6: Power consumption of the PAA solutions - Vessel II D = 0.445m; d/D = 0.50

Figure 7: Power consumption of the solution of PAA Vessel II D = 0.445m; d/D = 0.33

A simulation of the equation [II] is represented by figure 6 .It shows a reduction of power of the viscoelastic fluids compared to the Newtonian reference.

Figure 8 : simulation of power consumption for viscoelastic fluid

This simulation shows moreover two categories of viscoelastic :

- pseudoplastic and elastic fluids of category I, called PEFI , strongly viscous with weak natural times (guar 1,5%, CMC7H4C (1%;1,5%) which reduce the power to the beginning of the intermediate mode flow
- pseudoplastic and elastic fluids of the second category or PEFII marked with low viscosity and high natural time (aqueous PAA solutions) which reduce this one towards the end of the intermediate mode flow.

For the RFEI, the reduction of power, catch at least of the curves of power are in order from 20 to 40 %, while for the PEFII, it varies from 30 to 40 % according to the diameter and for value of Reynolds number higher than 1000. These results are comparable with those of the authors like : Nienow et al [7] which obtain reductions from 30 to 45% with of the Reynolds numbers ranging between 40 and 250 for CMC solution which are PEF I. Ranade [4] and Höcker et al [17] which obtain reductions from 42 to 60 % for solutions of PAA which are PEFII. For constants of Metzner-Otto, the curves of power consumption of the pure and pseudoplastics fluids (PPF), (characterized by a viscosimetric time and an elastic time no one) superimpose themselves perfectly on the Newtonian reference.

For the fluids of Boger (BFR), an increase of 300% of power is obtained in streamline flow, on the other hand, only 15% are obtained in intermediate mode. This result is comparable with that obtained by Prud'homme & collar [9]. For elastic pure fluids known as of Boger, an augmentation of the power in streamline flow, reveals a strong synergy between elasticity and pseudoplasticity.

Iv - Conclusion

The reduction of the viscoelastic power consumption in an unaereted mechanically agitated is rather more marked as its degree of elasticity increases

Two categories of viscoelastic fluids are put In evidence :

- fluids of the first category, the PEFI notablyy viscous with weak natural times (guar 1,5%, CMC7H4C 1%, 1, 5%) which reduce the power consumption to the beginning of the intermediairy mode flow
- fluids of the second category, the PEFII of low viscosity and high natural time (aqueous PAA solutions) which reduce this one towards the end of the intermediairy mode flow.

The precision of the correlation obtained of the power consumption reinforces the validity of the number of elasticity Elo to characterize the effect of the elastic properties

V - Nomenclature

A, B, C : constants of power consumption of newtonian fluid
An, Bn,Cn : constants of power consumption of viscoelastic fluid
d: diameter of the agitator
D: diameter of the tank
De: Deborah number
Elo: number of elasticity
kmo: Metzner-Otto constant
Kp: constant of power consumption in streamline flow
N: speed velocity of agitator
Np: power number
Npn: power number of Newtonian fluids
Npt: power number in turbulent flow of viscoelastic fluids
Nptn: power number in turbulent flow of Newtonian fluids
Npv: power number flow of viscoelastic fluid
Re: Reynolds number
Reg: generalized Reynolds number
tnωo: Characteristic time
Wi Weissenberg number

Greek numbers

η'; η''	real viscosity of rheologically complex fluid and imaginary viscosity
ηo	viscosity of the Newtonian plateau

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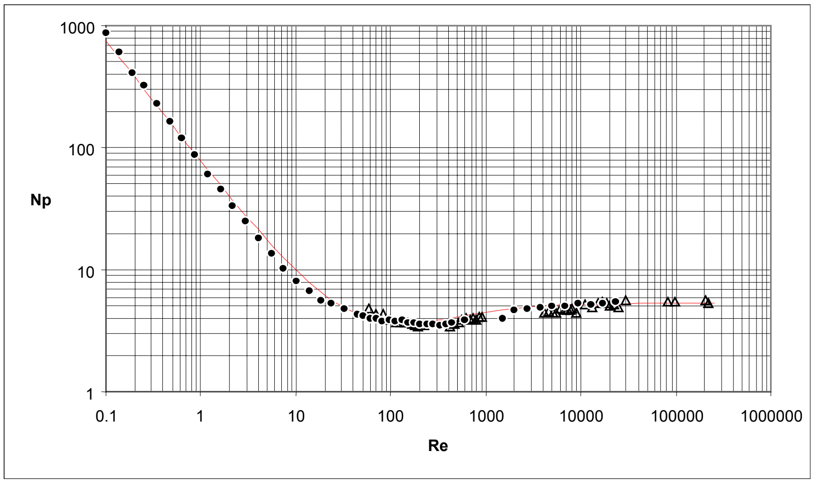
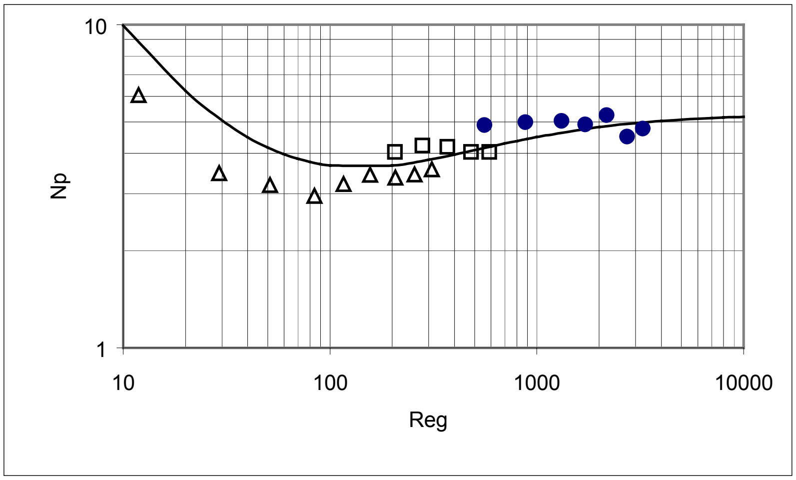


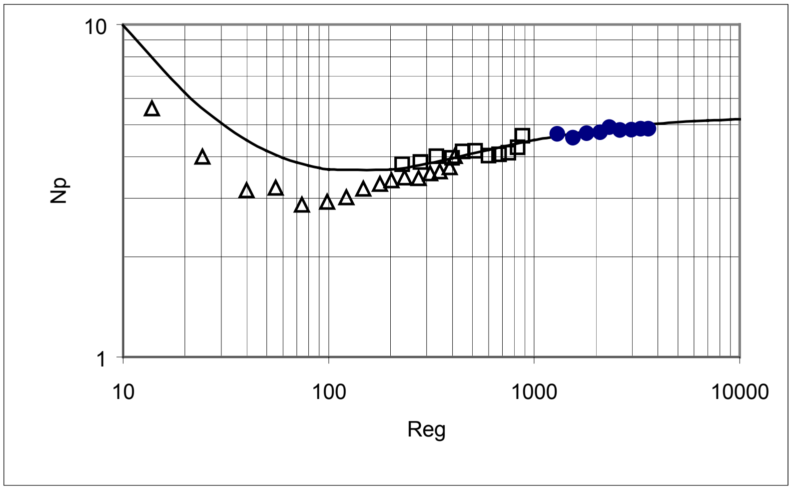
—— Npn △ Cuve II (D = 0.455m) ▪ Cuve I (D = 0.30m)

Figure 1: Power consumption of a fluid Newtonian



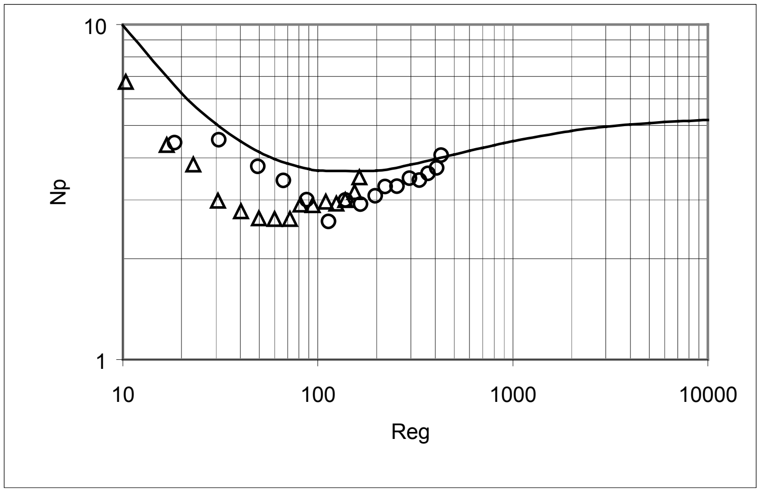
—— Npn ● Guar 0.50% ☐ Guar 1% △ Guar 1.5 %

Figure 2: Power consumption of the Guar solutions Vessel **II** D = 0,445m; d/D = 0,50



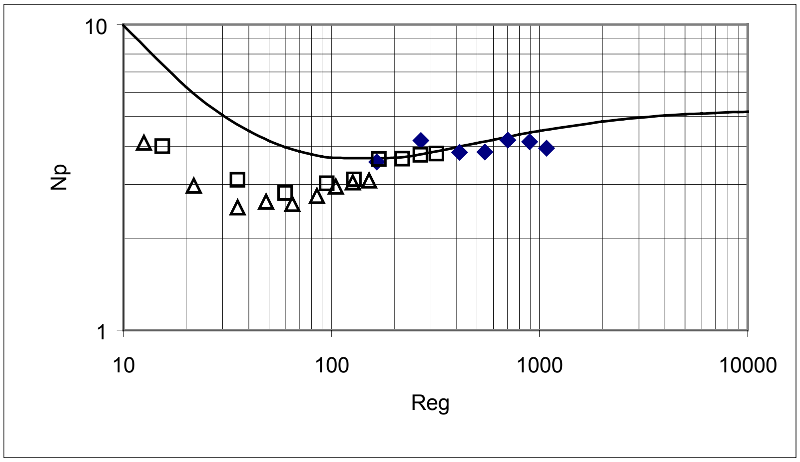
—— Npn ● Guar 0.50% □ Guar 1% Δ Guar 1.5 %

Figure 3: Power consumption of the Guar solution – Vessel II D = 0,445m; d/D = 0,33



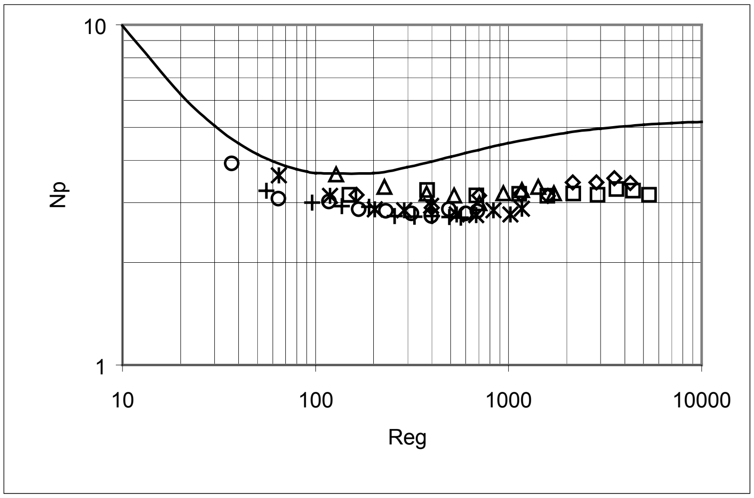
—— Npn ○ CMC 7H4 1% Δ CMC 7H4 1.5%

Figure 4: Power consumption of the CMC solutions – Vessel II D = 0.445m; d/D = 0.33



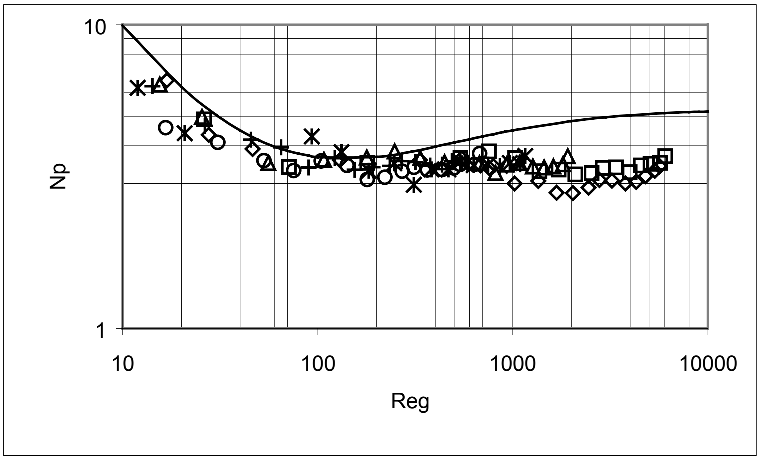
—— Npn ◆ CMC 7H4 0.50% ☐ CMC 7H4 1 % Δ CMC 7H4 1.5 %

Figure 5: Power consumption of the CMC solution - Vessel II D = 0.445m; d/D = 0.5



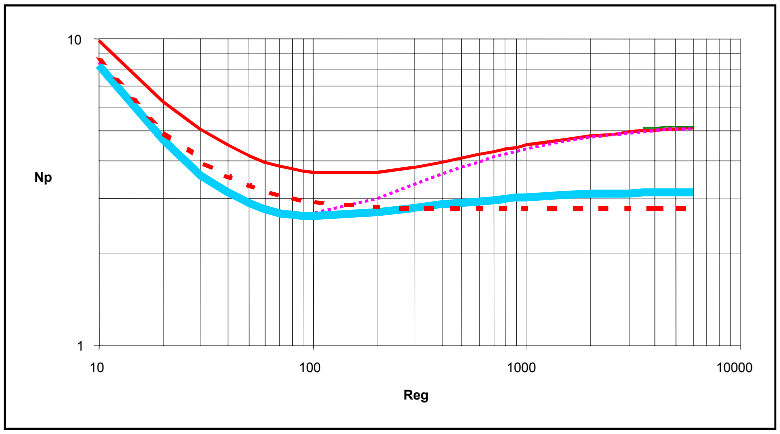
— Npn ◊PAA 0.1% ☐ PAA 0.20 % Δ PAA 0.30% ∗ PAA 0.50%
O PAA 0.75% + PAA 0.95%

Figure 6: Power consumption of the PAA solutions - Vessel II D = 0.445m; d/D = 0.50



— Npn ◊PAA 0.1% □ PAA 0.20 % ∆ PAA 0.30% ∗ PAA 0.50%
○ PAA 0.75% + PAA 0.95%,

Figure 7: Power consumption of the solution of PAA Vessel II D = 0.445m; d/D = 0.33



— Elo =0 ········ Elo = 2 ········ Elo = 20 ▬ Elo = 200

Figure 8 : simulation of power consumption for viscoelastic fluid