Fuel xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Viscoelastic properties and constitutive modelling of bitumen

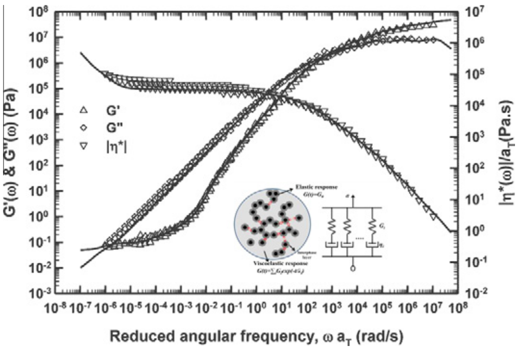
Ehsan Behzadfar, Savvas G. Hatzikiriakos *

Department of Chemical and Biological Engineering, The University of British Columbia, 2360 East Mall, Vancouver, British Columbia, V6T 1Z3, Canada

HIGHLIGHTS

- ▶ The linear viscoelastic behaviour of bitumen is studied in detail – relaxation modulus.
- ▶ The nonlinear rheological behaviour of bitumen was studied using the minimum number of rheological testing.
- ▶ A constitutive model was identified that captures the rheology of bitumen in a number of deformation histories.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 15 September 2012
Received in revised form 9 December 2012
Accepted 10 December 2012
Available online 25 December 2012

Keywords:
Bitumen
Viscosity
K-BKZ constitutive equation
Viscoelastic properties

ABSTRACT

In this paper, the viscoelastic behaviour of bitumen is studied and an appropriate and suitable constitutive equation is identified to describe its rheological behaviour. First, the generalised Maxwell model has been utilized to represent the relaxation modulus of bitumen and found to be in excellent agreement with experimental data over a wide range of temperatures (−30 °C to 90 °C). Furthermore, the time–temperature superposition principle was found to be applicable over this temperature range. The K-BKZ constitutive equation has been shown to represent accurately the rheological properties of bitumen. Analysis of experimental results revealed that either the Papanastasiou or the Marucci form of the damping function can be used in the K-BKZ constitutive equation. Moreover, the damping function was found to be independent of temperature (0–50 °C).

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

Bitumen is a viscoelastic multiphase material with colloidal microstructures consisted of elastic solid aggregates and a viscoelastic matrix. Based on the solubility parameters, bitumen components can be classified into four classes of saturates, aromatics, resins and asphaltenes. Whilst the dispersed solid phase in bitumen is mostly composed of high molecular weight asphaltenes, the matrix is a mixture of the maltenes (saturates, aromatics and resins) [1]. Depending on the thermo-mechanical conditions, these components are able to form distinctive structures inside bitumen, which are the origin of complications in rheological properties of bitumen, varying from entirely viscous behaviour to purely elastic behaviour [2,3].

Bitumen has found a plethora of applications due to its unique properties related to hydrophobicity, adhesion, and thermo-processability. The most obvious application is in road paving industry where it is used as a binder of asphalt mixtures. The broad window of applications makes it necessary to have sufficiently accurate rheological models to describe the flow properties of bitumen at different processing conditions, which is the main target of the present work. Although the linear viscoelasticity of bitumens and heavy oils has been of interest to many researchers [4–9], there have been few efforts in studying the nonlinear viscoelasticity of these materials, mainly reporting their shear thinning behaviour

---

* Corresponding author. Tel.: +1 604 822 3107.
E-mail address: savvas.hatzi@ubc.ca (S.G. Hatzikiriakos).

0016-2361/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.fuel.2012.12.035

Please cite this article in press as: Behzadfar E, Hatzikiriakos SG. Viscoelastic properties and constitutive modelling of bitumen. Fuel (2013), http://dx.doi.org/10.1016/j.fuel.2012.12.035

(viscous models) for bitumen [10–14]. However, based on the viscoelastic behaviour of these materials, to the best of our knowledge no studies exist on their viscoelastic constitutive modelling.

The first attempt to model the linear viscoelasticity of bitumen was performed by Van der Poel [4] followed by that of Heukolem and Klomp [5]. They utilized a nonlinear multivariable models (nomographs) to predict the stiffness modulus of bitumen having temperature, softening point, loading time and penetration index as inputs to their models. Improvements to this model were performed by McLeod in a series of papers [15]. Jongepier and Kuilman [16] developed an empirical algebraic equation to predict the rheological properties assuming that the relaxation spectrum of bitumen is log normal. Several other authors proposed empirical models to evaluate the linear viscoelastic properties of bitumen [6,7,17–23]. These models are basically algebraic equations, and their parameters have in general no physical meaning. This causes difficulties in gaining an understanding of the rheological response of these materials.

On the other hand, mechanical model offer a basic understanding of rheological behaviour and they are more attractive to use. Some of these mechanical models which have been used to model the rheological behaviour of bitumen are depicted in Fig. 1. These models include combinations of an ideal elastic spring (elastic modulus), a viscous dashpot (viscosity) and a parabolic element (creep compliance response) [24]. A generalised Burger model (Fig. 1a) is constructed by placing a Maxwell model in series with a number of Kelvin–Voigt models [25]. Huet [26] proposed a model in which a spring is in series with two parabolic elements (Fig. 1b). Sayegh [27] modified the Huet model (the Huet–Sayegh model) by putting a spring in parallel to the Huet model (Fig. 1c). Olard and Di Benedetto [28] constructed the DBN model by eliminating the Maxwell model's dashpot from the generalised Burger model (Fig. 1d). In other works, researchers have added a dashpot to the Huet–Sayegh model in series with the parabolic elements and in parallel with the separate spring to build the 2S2P1D model (Fig. 1e) [29,30]. These models may successfully model one type of experimental response (stress relaxation or creep), however, it is impossible to represent the complete rheological behaviours of the material by means of a simple mechanical model.

In the present study, the viscoelastic behaviour of bitumen is examined over a wide range of temperatures in an attempt to understand its complete rheological behaviour from elastic, to viscoelastic and to viscoelastoplastic in some cases. The generalised Maxwell model is used to model the linear viscoelastic properties of bitumen, which serves as a basis for our study of the nonlinear viscoelasticity. An appropriate constitutive equation is proposed to account for the rheological responses of bitumen at both linear and nonlinear viscoelastic regions over a wide range of temperatures. The proposed constitutive equation is examined and tested for a number of different deformation histories in order to determine its ability in predicting comprehensively the viscoelastic flow properties of bitumen.

2. Materials and methods

2.1. Material characterisation

The bitumen used in this study was obtained from Athabasca oil sands, Alberta, Canada with specific gravity of 0.969 at 22 °C. The asphaltene and maltenes (saturates, aromatics, resins) content of the bitumen were determined based on their solubility in n-pentane. The bitumen was mixed with n-pentane on the weight ratio of 1:40 and stirred overnight. The mixture was filtered twice by using paper filters of different pore sizes, namely 1–5 μm and 0.2 μm, respectively. Filtrations were accompanied with continuous vacuuming and extra solvent was used to make the filter paper colourless. The retentates were dried in an oven at 60 °C for 30 min and left in a vacuum oven at room temperature for 48 h. The permeates were placed in the rotary evaporator at 60 °C to remove out the n-pentane. The evaporator was kept running until no more n-pentane was collected. Both retentates and permeates were weighted to obtain the weight percentage of the asphaltenes and maltenes.

Elemental analysis of the sample was performed using the 2400 Perkin–Elmer CHNS/O Analyzer by combustion at 1000 °C. The oxygen content was calculated from subtraction based on the weight contents of the other elements. Metal analysis data were provided from the supplier based on ASTM-D5600. The bitumen was stored at ambient temperature before testing and neither phase dissociation nor evaporation occurred. The compositional and elemental analysis of the bitumen sample are summarised in Table 1.

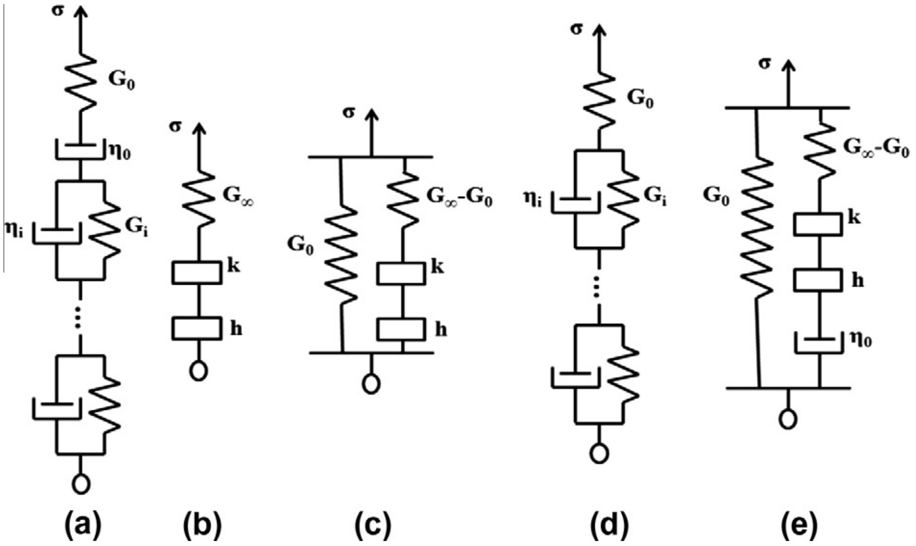


Fig. 1. Different viscoelastic mechanical models used for bitumen. (a) The generalised Burger model. (b) The Huet model. (c) The Huet–Sayegh model. (d) The DBN (Di Benedetto and Neifar) model. (e) The 2S2P1D model.

Please cite this article in press as: Behzadfar E, Hatzikiriakos SG. Viscoelastic properties and constitutive modelling of bitumen. Fuel (2013), http://dx.doi.org/10.1016/j.fuel.2012.12.035

Download English Version:

https://daneshyari.com/en/article/6641163

Download Persian Version:

https://daneshyari.com/article/6641163

Daneshyari.com