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ملخص الرسالة

إلى عهد قريب قامت الزيوت الخفيفة، كمصدر تقليدي للبترول الخام، بتوفير احتياجات العالم من مصادر اقتصادية الطاقة، ولكن في السنوات الأخيرة أدت الزيادة الكبيرة في الاستهلاك من المصادر التقليدية للزيت الخام نتيجة لتزايد الطلب على الطاقة، بالإضافة إلى انخفاض الاكتشافات الجديدة مما أدى إلى النقص الشديد في الاحتياطيات المؤكدة من البترول الخفيف، وضرورة البحث عن مصادر بديلة للطاقة. وتقدم مصادر الزيوت الخام الثقيلة والبيتومين البديل المناسب للطاقة على المدى القصير والبعيد. وتعتبر الزيوت الثقيلة والبيتومين من المصادر الغير تقليدية للطاقة وهى متوفرة على أعماق قريبة من السطح، وتؤكد التقديرات المتحفظة أن المخزون العالمي المؤكد للزيوت الثقيلة يقدر بما يزيد عن ستة تريليون برميل، وتمثل ما يقرب من ٧٠% من الاحتياطيات المؤكدة من مصادر الطاقة في العالم.

وقد أدي النقص الشديد في الاحتياطيات المؤكدة من المصادر التقليدية للبترول الخام إلى تنامي إنتاج واستخدام الزيوت الثقيلة والعمل على تطوير مصادرها، وتعتبر العقبة الرئيسية في استغلال مصادر الزيوت الثقيلة هي مقاومتها العالية للسريان بسبب اللزوجة الكبيرة لهذه الزيوت والتي قد تصل لآلاف المرات ضعف لزوجة الزيوت الخفيفة، والذي يؤدي بدوره إلى صعوبة أو استحالة نقلها خلال الأنابيب حيث تحتاج إلى طاقة ضخ كبيرة.

وقد استخدمت طرق تكنولوجية مختلفة لنقل الزيوت الثقيلة منها طرق لتخفيض لزوجة الزيت من خلال تسخين خطوط الأنابيب وهى طريقة مكلفة، وخلط الزيوت الثقيلة مع الزيوت الخفيفة أو المنتجات الهيدروكربونية، وفصلها بعد النقل. ويعتبر السريان الحلقي للماء حول الزيوت الثقيلة في أنابيب النقل من أرخص الطرق وأسهل الطرق تكنولوجياً وأكثرها كفاءة، حيث يتم حقن الماء حول الزيت الثقيل مكوناً مجرى حلقي يفصل بين السطح الداخلي لأنبوب النقل والزيت الخام المنقول، ويتميز هذا النوع من السريان بانخفاض المفاقيد الاحتكاكية والطاقة المطلوبة لضخ الزيت الثقيل، وبالتالي خفض تكلفة نقل الزيوت الثقيلة. وبمراجعة الدراسات السابقة تبين الحاجة إلى تقديم دراسات مستفيضة للسريان الحلقي للماء حول الزيوت الثقيلة خلال الأنابيب بغرض توضيح الكثير من الحقائق والمفاهيم المتعلقة بهذا النوع من السريان والحصول على المعلومات التي تساهم في الوصول إلى التصميم الأمثل لخطوط أنابيب النقل للزيوت الثقيلة.

وتقدم هذه الرسالة دراسة عددية للسريان الحلقي للماء حول الزيوت الثقيلة في خطوط الأنابيب الناقلة نتيجة لحقن الماء حلقياً حول الزيت الساري في قلب الأنبوب، بحيث يسري الماء حلقياً فاصلاً الزيت الثقيل عن السطح الداخلي للأنبوب، وذلك بغرض تخفيض المفاقيد الاحتكاكية، ودراسة تأثير العوامل المختلفة على تطور هيكل السريان، وعلى الفقد في الضغط والنقص في المفاقيد الاحتكاكية.

وقد استخدم برنامج ديناميكا الموائع الحسابية المعروف Fluent 6.3.16 لحل معادلات الحركة للسريان المضطرب للزيوت الثقيلة والماء في أنبوب بقطر ٦ بوصة. وقد تم استخدام عدد كبير من الزيوت الثقيلة تراوحت لزوجتها من ٣٠ إلى ١٨٠٠٠ سنتي بويز. كما تم تغيير نسبة قطر الزيت في قلب الأنبوب إلى القطر الداخلي للأنبوب ٠.٨٣، ٠.٩٢، ٠.٩٦ على الترتيب. كما تم دراسة العوامل المختلفة المؤثرة على تطور التوزيع المقطعي للسرعة، كثافة وطاقة الاضطراب.

وتوضح النتائج أن لزوجة الزيت الثقيل، معدل السريان، نسبة قطر الزيت في القلب إلى قطر الأنبوب، ونسبة كمية الماء إلى كمية الماء والزيت، وسرعة الماء إلى سرعة الزيت عند الدخول لها تأثير كبير على تطور هيكل السريان من لحظة حقن الماء حتى الوصول إلى التطور الكامل. وأنه كلما ارتفعت لزوجة الزيت الثقيل كلما أصبح التطور أسرع. كما توضح النتائج أن توزيع السرعة على أي مقطع كامل التطور أظهر سرعة ثابتة للزيت الثقيل في قلب الأنبوب بينما سرعة الماء في المقطع الحلقي تتغير من صفر على السطح إلى قيمة عظمى عند السطح الفاصل بين الماء والزيت، وأصبح الشكل العام للسريان كما لو كان الزيت الثقيل جسم صلب في قلب الأنبوب يحمله سريان الماء الحلقي المحيط به.

وتؤكد النتائج أن الفقد في الضغط والاحتكاك للسريان الحلقي للماء والزيت الثقيل أقل بكثير من تلك التي تم الحصول عليها في حالة سريان الزيت الثقيل وحده، وأنه تم توفير جزء كبير جداً من الطاقة المستخدمة في ضخ الزيت الثقيل بحقن كمية صغيرة من الماء حول الزيت الثقيل في أنبوب الحقن. كما توضح النتائج أن لزوجة الزيت الثقيل، معدل السريان، نسبة قطر الزيت في القلب إلى قطر الأنبوب، ونسبة كمية الماء إلى كمية الماء والزيت، وسرعة الماء إلى سرعة الزيت عند الدخول تؤثر تأثيراً كبيراً على قيمة الفقد في الضغط ومعامل الاحتكاك مقارنة بتلك المسجلة لسريان الزيوت الثقيلة وحدها في أنبوب النقل، وأنه كلما ارتفعت لزوجة الزيت الثقيل كلما أصبح الفارق بينهما كبيراً.

الرسالة مقدمة في سبعة فصول، إضافة إلى الملخص وقائمة المراجع وملحقين. وقد تم تخصيص الفصل الأول ليعطي مقدمة سريعة للزيت الخام الثقيل موضوع البحث وخصائصه والطرق التكنولوجية المستخدمة لنقله، كما يقدم للسريان الحلقي للماء والزيوت الثقيلة في أنابيب النقل ومدى الحاجة إلى دراسته، وفى الفصل الثاني تم عمل مراجعة للأبحاث السابقة في المجال لتغطي الكثير من الحالات التي تخص ذلك النوع من السريان.

ويغطي الفصل الثالث صياغة النموذج الرياضي المستخلص لتوصيف السريان الحلقي للماء حول الزيت الثقيل في أنبوب النقل، حيث تم توصيف معادلات السريان وكمية الحركة ونموذج الاضطراب المستخدم $k-\omega$ لحل معادلات نافيير–ستوكس للسريان الحلقي المضطرب لمائعين مختلفي اللزوجة، كما ناقش الفصل معالجة منطقة السطح والشروط الحدودية. ويناقش الفصل الرابع طريقة الحجم المحدودة Finite-volume المستخدمة للحصول علي الحل العددي لمعادلات نافيير–ستوكس ومعادلات نموذج الاضطراب $k-\omega$، كما

يناقش مجموعة برامج ديناميكا الموائع الحسابية Fluent CFD Package واستخدامها لتمثيل السريان الحلقي المضطرب للماء حول الزيت الثقيل في أنبوب النقل. ويقدم الفصل الخامس مناقشة لتقييم نتائج النموذج الرياضي مع النتائج المعملية المتاحة لبيان صلاحيته وقدرته على معالجة السريان الحلقي للماء حول الزيت الثقيل في أنبوب النقل.

ويقدم الفصل السادس عرض ومناقشة لنتائج دراسة السريان الحلقي للماء والزيت الثقيل في أنبوب النقل، ويناقش هذا الفصل تأثير العوامل المختلفة على تطور هيكل السريان للزيوت الثقيلة في خطوط الأنابيب الناقلة نتيجة لحقن الماء حلقياً حول الزيت الساري في قلب الأنبوب، بحيث يسري الماء حلقياً فاصلاً الزيت الثقيل عن السطح الداخلي للأنبوب، وذلك بغرض تخفيض المفاقيد الاحتكاكية، كما يناقش تأثير العوامل المختلفة على الفقد في الضغط والنقص في المفاقيد الاحتكاكية، ويناقش هذا الباب أيضا التوفير المحقق فى الطاقة المستخدمة لضخ الزيوت الثقيلة فى خطوط الانابيب بإستخدام طريقة حقن الماء حلقياً حول الزيت الساري في قلب الأنبوب.

وفي النهاية يقدم الفصل السابع من هذه الرسالة ملخصاً سريعاً لموضوع البحث، كما يقدم أهم الاستنتاجات العلمية التي تم استخلاصها من هذه الدراسة، وتختتم الرسالة بأهم المقترحات لاستكمال البحث والدراسات المستقبلية في هذا المجال.

Abstract

Conserved estimates show that heavy oil reserves are estimated to be more than six trillion barrels throughout the world. Their importance tends to increase progressively, as light oil fields are exhausting. The progressive increase of oil demand coupled with the depletion of light crude oils has led to the rapid development of the large world resources of heavy oils. Production of heavy crudes is increasing significantly as low viscosity crudes are depleted. The production of hydrocarbons from heavy oil and bitumen (oil sands) reserves increases annually. The main problem is their high flow resistance caused by the high viscosity. This makes its transportation almost impossible, due to the immense power requirement.

Water lubricated transport of heavy oil is an effective technique for the pipeline transportation of such high viscosity oils. Water is injected into the oil pipelines such that it flows as annular film encapsulating the oil in the core region. Such flow is well known as oil-water core annular pipe flow. Water is acting as lubricant for heavy oils transport in pipeline. Since oil does not come in contact with the wall, the wall shear is comparable to the shear encountered during the flow of water in the pipe. This reduces drastically the pumping power and the cost of transportation of heavy oil and bitumen.

Literature review reveals that there is limited number of numerical studies concerning the core annular flows of heavy oils and water. Many aspects need to be clarified such as flow structure and the influence of different parameters on pressure reduction. In this work, study of the core annular flow of heavy oils and water in a pipe is presented. Numerical simulation of the axisymmetric laminar core, turbulent annular flow is carried out using the standard k–ω model. The flow field and flow characteristics are investigated using Fluent 6.32 CFD package. The core annular flow of heavy oils water in 15.24 cm diameter pipe is considered. The influence of different core annular flow parameters upon pressure gradient and friction coefficient is investigated. Flow parameters considered are flow Reynolds number, oil to water viscosity ratio, water to oil volume ratio, core to pipe diameters ratio, and oil and water superficial velocity. Oil and water flow development is also investigated.

Flow structure investigation demonstrated that major changes in flow structure occur at the oil-water interface. The fully-developed velocity profile of oil-water core annular flow exhibits distinguishable core and annular regions, and the oil velocity profile in the core region is almost constant with little variations, while in the annulus it looks like a turbulent one with sharp increase near the wall to maximum at oil-water interface. For heavy oils with viscosity $\mu > 3000$ cP, velocity profile exhibits constant distribution in the oil core and the core looks like a rigid body carried by the annular water flow.

Results show that the pressure drop and friction losses of the oil-water core annular flow is much smaller compared to those of oils flowing alone in the pipeline. That means saving a lot of pumping power is achieved when injecting small amount of water to encapsulate heavy oil in the pipe core. Results of oil-water core annular flow exhibit better reduction in friction loss in pipes with thicker water annulus.

It has been demonstrated that friction coefficient C_f of heavy oil pipe flow, as single phase, is in full agreement with the well-known Blasius relation $C_f = 16/Re$. For the results presented in this work, the friction coefficient C_f of the heavy oil-water core annular flow is best fitted by the relation $C_f = 0.003.Re_o{}^{0.012}$.

Results show that the reduction in pressure gradient ratio Φ and friction coefficient ratio β of oil-water flow increases with the viscosity of the heavy oil μ_r. The pressure gradient ratio Φ is best fitted to oil's viscosity (μ_r) by the relation $\Phi = 0.126.[\mu_r]^{0.7}$, whereas the friction coefficient ratio β is best fitted by $\beta = 0.083.[\mu_r]^{0.77}$. The results of Φ, and β are best fitted to oil based Reynolds number as, $\Phi = 1016/\mathrm{Re}_o{}^{0.71}$ and $\beta = 1515/\mathrm{Re}_o{}^{0.77}$showing that they are inversely proportional to the relative viscosity $\mu_{r)}$

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by

Eng. Ahmed Lotfy Hassan Rabie Sakr

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Dedication

To my father ***Prof. Dr. Lotfy Sakr*** for being a wonderful dad

Specially dedicated to my wife, ***Amany El-Shal,*** for her support and encouragement during the time when I was busy with my studies, and to my little angles ***Hala*** and ***Marawan***.

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Abstract

Conserved estimates show that heavy oil reserves are estimated to be more than six trillion barrels throughout the world. Their importance tends to increase progressively, as light oil fields are exhausting. The progressive increase of oil demand coupled with the depletion of light crude oils has led to the rapid development of the large world resources of heavy oils. Production of heavy crudes is increasing significantly as low viscosity crudes are depleted. The production of hydrocarbons from heavy oil and bitumen (oil sands) reserves increases annually. The main problem is their high flow resistance caused by the high viscosity. This makes its transportation almost impossible, due to the immense power requirement.

Water lubricated transport of heavy oil is an effective technique for the pipeline transportation of such high viscosity oils. Water is injected into the oil pipelines such that it flows as annular film encapsulating the oil in the core region. Such flow is well known as oil-water core annular pipe flow. Water is acting as lubricant for heavy oils transport in pipeline. Since oil does not come in contact with the wall, the wall shear is comparable to the shear encountered during the flow of water in the pipe. This reduces drastically the pumping power and the cost of transportation of heavy oil and bitumen.

Literature review reveals that there is limited number of numerical studies concerning the core annular flows of heavy oils and water. Many aspects need to be clarified such as flow structure and the influence of different parameters on pressure reduction. In this work, study of the core annular flow of heavy oils and water in a pipe is presented. Numerical simulation of the axisymmetric laminar core, turbulent annular flow is carried out using the standard *k*–ω model. The flow field and flow characteristics are investigated using Fluent 6.32 CFD package. The core annular flow of heavy oils water in 15.24 cm diameter pipe is considered. The influence of different core annular flow parameters upon pressure gradient and friction coefficient is investigated. Flow parameters considered are flow Reynolds number, oil to water viscosity ratio, water to oil volume ratio, core to pipe diameters ratio, and oil and water superficial velocity. Oil and water flow development is also investigated.

Flow structure investigation demonstrated that major changes in flow structure occur at the oil-water interface. The fully-developed velocity profile of oil-water core annular flow exhibits distinguishable core and annular regions, and the oil velocity profile in the core region is almost constant with little variations, while in the annulus it looks like a turbulent one with sharp increase near the wall to maximum at oil-water interface. For heavy oils with viscosity $\mu > 3000$ cP, velocity profile exhibits constant distribution in the oil core and the core looks like a rigid body carried by the annular water flow.

Results show that the pressure drop and friction losses of the oil-water core annular flow is much smaller compared to those of oils flowing alone in the pipeline. That means saving a lot of pumping power is achieved when injecting small amount of water to encapsulate heavy oil in the pipe core. Results of oil-water core annular flow exhibit better reduction in friction loss in pipes with thicker water annulus.

It has been demonstrated that friction coefficient C_f of heavy oil pipe flow, as single phase, is in full agreement with the well-known Blasius relation $C_f = 16/Re$. For the results presented in this work, the friction coefficient C_f of the heavy oil-water core annular flow is best fitted by the relation $C_f = 0.003.Re_o{}^{0.012}$.

Results show that the reduction in pressure gradient ratio Φ and friction coefficient ratio β of oil-water flow increases with the viscosity of the heavy oil μ_r. The pressure gradient ratio Φ is best fitted to oil's viscosity (μ_r) by the relation $\Phi = 0.126.[\mu_r]^{0.7}$, whereas the friction coefficient ratio β is best fitted by $\beta = 0.083.[\mu_r]^{0.77}$. The results of Φ, and β are best fitted to oil based Reynolds number as, $\Phi = 1016/\mathrm{Re}_o{}^{0.71}$ and $\beta = 1515/\mathrm{Re}_o{}^{0.77}$showing that they are inversely proportional to the relative viscosity $\mu_{r)}$

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