Pearson BTEC Level 4 Higher Nationals in Engineering (RQF)

Unit 11: Fluid Mechanics

Unit Workbook 2

in a series of 4 for this unit

Learning Outcome 2

Viscosity

Contents

INTRODUCTION

Examine the operating principles and limitations of viscosity measuring devices

- *Viscosity in fluids:*
    - Dynamic and kinematic viscosity definitions.
    - Characteristics of Newtonian fluids.
    - Temperature effects on viscosity.
    - Classification of non-Newtonian fluids.
- *Operating principles and limitations:*
    - Operating principles of viscometers.
    - Converting results acquired from viscometers into viscosity values.

GUIDANCE

This document is prepared to break the unit material down into bite size chunks. You will see the learning outcomes above treated in their own sections. Therein you will encounter the following structures;

Purpose

Explains *why* you need to study the current section of material. Quite often learners are put off by material which does not initially seem to be relevant to a topic or profession. Once you understand the importance of new learning or theory you will embrace the concepts more readily.

Theory

Conveys new material to you in a straightforward fashion. To support the treatments in this section you are strongly advised to follow the given hyperlinks, which may be useful documents or applications on the web.

Example

The examples/worked examples are presented in a knowledge-building order. Make sure you follow them all through. If you are feeling confident then you might like to treat an example as a question, in which case cover it up and have a go yourself. Many of the examples given resemble assignment questions which will come your way, so follow them through diligently.

Question

Questions should not be avoided if you are determined to learn. Please do take the time to tackle each of the given questions, in the order in which they are presented. The order is important, as further knowledge and confidence is built upon previous knowledge and confidence. As an Online Learner it is important that the answers to questions are immediately available to you. Contact your Unit Tutor if you need help.

Challenge

You can really cement your new knowledge by undertaking the challenges. A challenge could be to download software and perform an exercise. An alternative challenge might involve a practical activity or other form of research.

Video

Videos on the web can be very useful supplements to your distance learning efforts. Wherever an online video(s) will help you then it will be hyperlinked at the appropriate point.

2.1 Viscosity

Viscosity is a fluid's resistance to deformation under shear stresses.

Viscosity is an important property of any fluid, as it also helps determine its behaviour and motion against solid boundaries (such as pipes, gears, sliding contacts etc.). The viscosity is determined by the inter-molecular friction that is seen when one layer slides over the other. Or to put it simply, ***viscosity is how runny the fluid is***. The higher the viscosity, the thicker, and less runny, the fluid is.

It is very important to note that viscosity is temperature dependent. When considering a shortlist of fluids to a given application, it is vital that the temperature of the system is also considered.

2.1.1 Dynamic Viscosity

Dynamic viscosity is the fluid's resistance to flow when an external force is applied. Dynamic viscosity can be thought of as the tangential force per unit area required to move one plane (layer) of fluid with respect to another. The velocity between layers of a laminar fluid moving in straight parallel lines for a Newtonian fluid can be seen in Fig.2.1.

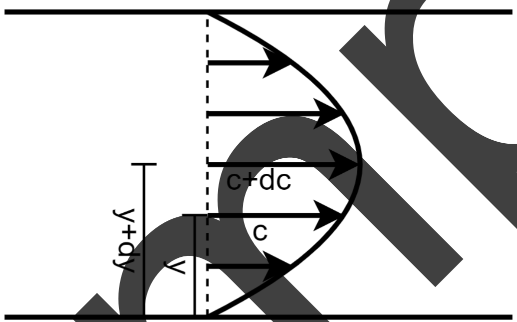

Figure 2.1: Velocity between layers of a laminar fluid

The shear stress τ can be defined by Eq.2.1, where μ is the dynamic viscosity, c is the velocity of the fluid, y is the height from the surface. dc/dy is also known as the "shear rate".

$$\tau = \mu \frac{dc}{dy} \qquad (2.1)$$

The SI units for dynamic viscosity is $\mathrm{Pa \cdot s}$, the values used are typically very low (e.g., the dynamic viscosity of water at $20^{\circ}\mathrm{C}$ is $0.0010005\ \mathrm{Pa \cdot s}$. More commonly the units that are used are the Poise, P, or centipoise, cP, where $10\ \mathrm{P} = 1\ \mathrm{Pa \cdot s}$, therefore the dynamic viscosity of water at $20^{\circ}\mathrm{C}$ is $0.010005\ \mathrm{P}$ or $1.0005\ \mathrm{cP}$.

2.1.2 Kinematic Viscosity

Kinematic viscosity is the fluid's resistive flow under its own weight (no external forces are applied, just gravity). The substance with the highest kinematic viscosity is tar pitch, which, despite appearing to be a solid and even shatters when it is hit with a hammer, is actually an incredibly viscous liquid, and will drip roughly once every ten years. An experiment widely recognised as the longest running in the University of Queensland, Australia, is analysing the drip of tar pitch and began in 1927. Since the drip occurs around once every ten years, it has never actually been seen; the last time it did drip, the webcam failed and missed it.

Kinematic viscosity, ν, can be calculated using Eq.2.2, where ρ is the density of the fluid

2.1.4.1 $\mathrm{VI} < 100$

In the majority of cases, and for examples within this unit we will only be looking at lubricants with a Viscosity Index (VI) of less than 100.

To calculate the VI, there are two pieces of information which must be known from the start; the Kinematic Viscosity (KV) at 40°C and at 100°C. The KV at 40°C is noted as U and the KV at 100°C is noted as Y in the following method.

If the value of KV at 100°C is between 2 cSt and 70 cSt then the table opposite is used to look up the corresponding values of 'L' and 'H', these letters merely signify some constants of viscosity at certain predefined temperatures. If the KV at 100°C is above the value of 70 cSt then the table is not used to find 'L' and 'H', but rather a separate formula is used, as follows:

$$\mathrm{L} = 0.8353\mathrm{Y}^2 + 14.67\mathrm{Y} - 216 \quad (2.3)$$

$$\mathrm{H} = 0.1684\mathrm{Y}^2 + 11.85\mathrm{Y} - 97 \quad (2.4)$$

The viscosity index in either case is then calculated using Eq.2.5:

$$\mathrm{VI} = 100\frac{\mathrm{L} - \mathrm{U}}{\mathrm{L} - \mathrm{H}} \quad (2.5)$$

2.1.4.2 $VI > 100$

In the rare case that lubricants have a viscosity index greater than 100, then the following steps need to be taken.

1. Determine the kinematic viscosity of the sample at 40°C and 100°C
2. Determine the value of H
   i. If $2\ \mathrm{mm}^2/s < \mathrm{Y} < 70\ \mathrm{mm}^2/s$, the ATSM standards can be used; these values are shown in Table 2.1.
   ii. If $70\ \mathrm{mm}^2/s < Y$, then H is calculated using Eq.2.4:
3. The viscosity index is therefore given as Eq.2.6:

$$\mathrm{VI} = \frac{10^{\mathrm{N}} - 1}{0.00715} + 100 \quad (2.6)$$

Where:

$$\mathrm{N} = \frac{\log_{10}\mathrm{H} - \log_{10}\mathrm{U}}{\log_{10}\mathrm{Y}} \quad (2.7)$$

Table 2.1: ATSM values for L and H for the sample oil of viscosity between $2 - 70mm^2/s$

Kinematic Viscosity at 100°C, mm^2/s (cSt)	*L*	*H*	Kinematic Viscosity at 100°C, mm^2/s (cSt)	*L*	*H*	Kinematic Viscosity at 100°C, mm^2/s (cSt)	*L*	*H*	Kinematic Viscosity at 100°C, mm^2/s (cSt)	*L*	*H*	Kinematic Viscosity at 100°C, mm^2/s (cSt)	*L*	*H*	Kinematic Viscosity at 100°C, mm^2/s (cSt)	*L*	*H*
2.00	7.994	6.394	7.00	78.00	48.57	12.0	201.9	108.0	17.0	369.4	180.2	24.0	683.9	301.8	42.5	1935	714.9
2.10	8.640	6.894	7.10	80.25	49.61	12.1	204.8	109.4	17.1	373.3	181.7	24.2	694.5	305.6	43.0	1978	728.2
2.20	9.309	7.410	7.20	82.39	50.69	12.2	207.8	110.7	17.2	377.1	183.3	24.4	704.2	309.4	43.5	2021	741.3
2.30	10.00	7.944	7.30	84.53	51.78	12.3	210.7	112.0	17.3	381.0	184.9	24.6	714.9	313.0	44.0	2064	754.4
2.40	10.71	8.496	7.40	86.66	52.88	12.4	213.6	113.3	17.4	384.9	186.5	24.8	725.7	317.0	44.5	2108	767.6
2.50	11.45	9.063	7.50	88.85	53.98	12.5	216.6	114.7	17.5	388.9	188.1	25.0	736.5	320.9	45.0	2152	780.9
2.60	12.21	9.647	7.60	91.04	55.09	12.6	219.6	116.0	17.6	392.7	189.7	25.2	747.2	324.9	45.5	2197	794.5
2.70	13.00	10.25	7.70	93.20	56.20	12.7	222.6	117.4	17.7	396.7	191.3	25.4	758.2	328.8	46.0	2243	808.2
2.80	13.80	10.87	7.80	95.43	57.31	12.8	225.7	118.7	17.8	400.7	192.9	25.6	769.3	332.7	46.5	2288	821.9
2.90	14.63	11.50	7.90	97.72	58.45	12.9	228.8	120.1	17.9	404.6	194.6	25.8	779.7	336.7	47.0	2333	835.5
3.00	15.49	12.15	8.00	100.0	59.60	13.0	231.9	121.5	18.0	408.6	196.2	26.0	790.4	340.5	47.5	2380	849.2
3.10	16.36	12.82	8.10	102.3	60.74	13.1	235.0	122.9	18.1	412.6	197.8	26.2	801.6	344.4	48.0	2426	863.0
3.20	17.26	13.51	8.20	104.6	61.89	13.2	238.1	124.2	18.2	416.7	199.4	26.4	812.8	348.4	48.5	2473	876.9
3.30	18.18	14.21	8.30	106.9	63.05	13.3	241.2	125.6	18.3	420.7	201.0	26.6	824.1	352.3	49.0	2521	890.9
3.40	19.12	14.93	8.40	109.2	64.18	13.4	244.3	127.0	18.4	424.9	202.6	26.8	835.5	356.4	49.5	2570	905.3
3.50	20.09	15.66	8.50	111.5	65.32	13.5	247.4	128.4	18.5	429.0	204.3	27.0	847.0	360.5	50.0	2618	919.6
3.60	21.08	16.42	8.60	113.9	66.48	13.6	250.6	129.8	18.6	433.2	205.9	27.2	857.5	364.6	50.5	2667	933.6
3.70	22.09	17.19	8.70	116.2	67.64	13.7	253.8	131.2	18.7	437.3	207.6	27.4	869.0	368.3	51.0	2717	948.2
3.80	23.13	17.97	8.80	118.5	68.79	13.8	257.0	132.6	18.8	441.5	209.3	27.6	880.6	372.3	51.5	2767	962.9
3.90	24.19	18.77	8.90	120.9	69.94	13.9	260.1	134.0	18.9	445.7	211.0	27.8	892.3	376.4	52.0	2817	977.5
4.00	25.32	19.56	9.00	123.3	71.10	14.0	263.3	135.4	19.0	449.9	212.7	28.0	904.1	380.6	52.5	2867	992.1
4.10	26.50	20.37	9.10	125.7	72.27	14.1	266.6	136.8	19.1	454.2	214.4	28.2	915.8	384.6	53.0	2918	1007
4.20	27.75	21.21	9.20	128.0	73.42	14.2	269.8	138.2	19.2	458.4	216.1	28.4	927.6	388.8	53.5	2969	1021
4.30	29.07	22.05	9.30	130.4	74.57	14.3	273.0	139.6	19.3	462.7	217.7	28.6	938.6	393.0	54.0	3020	1036
4.40	30.48	22.92	9.40	132.8	75.73	14.4	276.3	141.0	19.4	467.0	219.4	28.8	951.2	396.6	54.5	3073	1051
4.50	31.96	23.81	9.50	135.3	76.91	14.5	279.6	142.4	19.5	471.3	221.1	29.0	963.4	401.1	55.0	3126	1066
4.60	33.52	24.71	9.60	137.7	78.08	14.6	283.0	143.9	19.6	475.7	222.8	29.2	975.4	405.3	55.5	3180	1082
4.70	35.13	25.63	9.70	140.1	79.27	14.7	286.4	145.3	19.7	479.7	224.5	29.4	987.1	409.5	56.0	3233	1097
4.80	36.79	26.57	9.80	142.7	80.46	14.8	289.7	146.8	19.8	483.9	226.2	29.6	998.9	413.5	56.5	3286	1112
4.90	38.50	27.53	9.90	145.2	81.67	14.9	293.0	148.2	19.9	488.6	227.7	29.8	1011	417.6	57.0	3340	1127
5.00	40.23	28.49	10.0	147.7	82.87	15.0	296.5	149.7	20.0	493.2	229.5	30.0	1023	421.7	57.5	3396	1143
5.10	41.99	29.46	10.1	150.3	84.08	15.1	300.0	151.2	20.2	501.5	233.0	30.5	1055	432.4	58.0	3452	1159
5.20	43.76	30.43	10.2	152.9	85.30	15.2	303.4	152.6	20.4	510.8	236.4	31.0	1086	443.2	58.5	3507	1175
5.30	45.53	31.40	10.3	155.4	86.51	15.3	306.9	154.1	20.6	519.9	240.1	31.5	1119	454.0	59.0	3563	1190
5.40	47.31	32.37	10.4	158.0	87.72	15.4	310.3	155.6	20.8	528.8	243.5	32.0	1151	464.9	59.5	3619	1206
5.50	49.09	33.34	10.5	160.6	88.95	15.5	313.9	157.0	21.0	538.4	247.1	32.5	1184	475.9	60.0	3676	1222
5.60	50.87	34.32	10.6	163.2	90.19	15.6	317.5	158.6	21.2	547.5	250.7	33.0	1217	487.0	60.5	3734	1238
5.70	52.64	35.29	10.7	165.8	91.40	15.7	321.1	160.1	21.4	556.7	254.2	33.5	1251	498.1	61.0	3792	1254
5.80	54.42	36.26	10.8	168.5	92.65	15.8	324.6	161.6	21.6	566.4	257.8	34.0	1286	509.6	61.5	3850	1270
5.90	56.20	37.23	10.9	171.2	93.92	15.9	328.3	163.1	21.8	575.6	261.5	34.5	1321	521.1	62.0	3908	1286
6.00	57.97	38.19	11.0	173.9	95.19	16.0	331.9	164.6	22.0	585.2	264.9	35.0	1356	532.5	62.5	3966	1303
6.10	59.74	39.17	11.1	176.6	96.45	16.1	335.5	166.1	22.2	595.0	268.6	35.5	1391	544.0	63.0	4026	1319
6.20	61.52	40.15	11.2	179.4	97.71	16.2	339.2	167.7	22.4	604.3	272.3	36.0	1427	555.6	63.5	4087	1336
6.30	63.32	41.13	11.3	182.1	98.97	16.3	342.9	169.2	22.6	614.2	275.8	36.5	1464	567.1	64.0	4147	1352
6.40	65.18	42.14	11.4	184.9	100.2	16.4	346.6	170.7	22.8	624.1	279.6	37.0	1501	579.3	64.5	4207	1369
6.50	67.12	43.18	11.5	187.6	101.5	16.5	350.3	172.3	23.0	633.6	283.3	37.5	1538	591.3	65.0	4268	1386
6.60	69.16	44.24	11.6	190.4	102.8	16.6	354.1	173.8	23.2	643.4	286.8	38.0	1575	603.1	65.5	4329	1402
6.70	71.29	45.33	11.7	193.3	104.1	16.7	358.0	175.4	23.4	653.8	290.5	38.5	1613	615.0	66.0	4392	1419
6.80	73.48	46.44	11.8	196.2	105.4	16.8	361.7	177.0	23.6	663.3	294.4	39.0	1651	627.1	66.5	4455	1436
6.90	75.72	47.51	11.9	199.0	106.7	16.9	365.6	178.6	23.8	673.7	297.9	39.5	1691	639.2	67.0	4517	1454
												40.0	1730	651.8	67.5	4580	1471
												40.5	1770	664.2	68.0	4645	1488
												41.0	1810	676.6	68.5	4709	1506
												41.5	1851	689.1	69.0	4773	1523
												42.0	1892	701.9	69.5	4839	1541
															70.0	4905	1558