Experimental Analysis on Francis Turbine at Optimum Load for the Performance Characteristics Curves

Aung Zaw Lynn, Cho Cho Khaing, Than Naing Win
Department of Mechanical Engineering, Technological University Mandalay, Myanmar

***Abstract*- This paper is written to put forward the facts and findings obtained from the test of a Francis turbine setup in the hydraulic lab of YTU. The purpose of the test is to draw the performance curves of the turbine. Since the supply head of the turbine cannot be specifically set it is run under pressure head 15 feet with its gates kept open at eight different positions. The performance curves obtained show that the maximum efficiency at 15 feet is approximately 80 percent. A maximum output of 2.3 b.h.p was obtained under the experimental conditions. The results obtained were graphically plotted and the curves obtained are known as constant head characteristics curve. This paper focuses mainly on the experimental analysis to get actual performance characteristics curves.The brake horse power is calculated for each part loads. After the completion of the experiment, a curve is plotted between unit discharge and unit speed for Francis turbine in every gate opening. This curves represent only for 60%, 70%, 75% and 78% with five different gate opening. The curves between efficiency and unit power are rising curves significantly in 75% gate opening and 50% gate opening. The unit brake power is optimum in 75% gate opening. Also it is being that the same efficiencies curves at different speed and discharge in each of gate opening. Furthermore, it was mentioned the curves were plotted with unit speed and efficiency and with unit power and efficiency too.**

***Key words:* efficiency, Francis Turbine, head, speed, Power**

I. INTRODUCTION

Francis turbines are inward flow reaction turbine. The flow was radial discharge in old Francis turbine. The modern Francis turbine is an inward mixed flow (radial and axial) reaction turbine. In this turbine, water under pressure enters the runner through the guide blade radially in inward flow direction and leaves the axial direction from runner.

The turbine runner consists of a curved vanes uniformly fitted around the runner cone and ring. The vanes are smooth and their profile varies from inlet to outlet depend on the designed head. Water from the reservoir is led to the turbine through the penstock.Thewater from the penstock enters "scroll casing" which surrounds the guide vanes and the runner. These guide vanes may be controlled by a governor on desired load. As thewater flows through the guide vanes, water radially in volute strikes the runner blades and causes the runner to rotate. After doing work in the runner vanes, water leaves the turbine axially through a straight divergent cone, called "draft tube" and finally flows through the tail race.The draft tube is to decelerate the velocity and increase the pressure of the fluid flowing from the runner exit to tail race.

In any reaction turbine the water at inlet possesses both pressure energy and kinetic energy. As the water flows through the turbine its pressure energy is transformed into kinetic energy and ultimately energy this water leaves the turbine at atmospheric pressure or at a pressure greater than atmospheric pressure.

The runner of the turbine is enclosed in an air-tight casing and the runner is full of water. Reaction turbines are also called pressure turbines.Francis turbine is widely used all over the world. It operates under the head varying from 30 to 500 m. The single unit may develop power as high as 750 MW output. The specific speed ranges from 60 to 400. Formerly its specific speed was limited to about 60 and it was radial inward flow type but at present they are the mixed flow type with radial flow at entry and axial flow at exit.

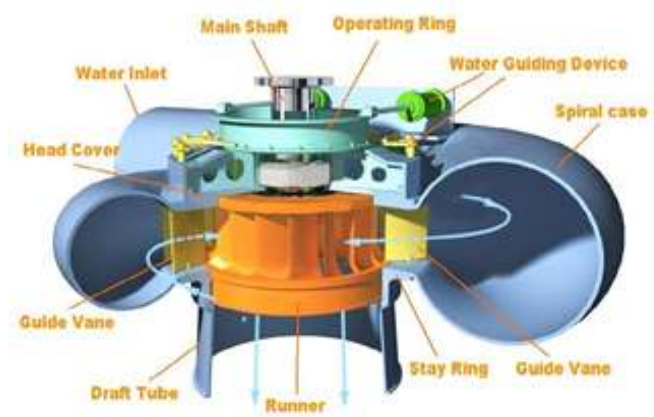

Fig. 1Sectional view of Francis Turbine

II. DESCRIPTION OF EXPERIMENTAL SET-UP

The description of experimental set up is horizontal shaft type Francis turbine. It consists of main components such as runner, volute casing, guide vanes, draft tube, sump tank and other accessory gauges arranged in a way that the whole unit works on recirculating water system. The water reaches the guide blade through penstock by a auxiliary pump. As the water flows over the vanes the pressure head is gradually converted into velocity head. This kinetic energy is utilized in rotating the wheel and thus the hydraulic energy is converted into mechanical energy. The outgoing water enters the tail race after passing through the draft tube. The enlarged end is submerged deeply in the tail race water at sump tank. The turbine has a Bourdon pressure gauge fitted to its spiral casing. The output power of the turbine is computed from the torque applied to the brake drum. The following figure is shown Francis Turbine experimental set up in fluid mechanics laboratory at YTU.

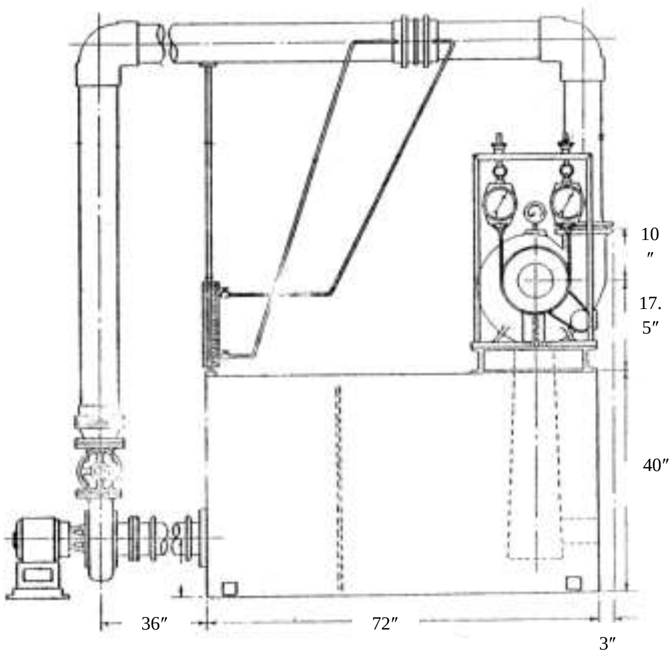

Fig. 2Francis Turbine experimental set up in fluid mechanics laboratory

A. Specifications of Francis Turbine

The specifications of Francis turbine are as follow;

Runner diameter	= 6 inches
No. of blade	= 17 blades,
Net head	= 70 feet
Flow rate	= 218 gpm
Normal speed	= 2000 rpm
Power	= 3.4 bhp
Specific speed	= 18.2
Flow rate	= Q 80.8 m^3/s
Gross weight	= 450 lb
Brake drum diameter	= 12 inches
Volume	= 28 ft^3

III. EXPERIMENTATION METHODOLOGY

The trials were conducted on Francis Turbine test set up to evaluate the performance and to obtain the constant head characteristic curves at different load conditions. The guide vane angle position was selected. The gate was closed before starting the pump. The guide vane is kept for the required position by adjustable wheel. The gate was opened slowly so that turbine rotor picks up the speed and attains maximum at opening of the gate and set pressure on the gauge. For different loads, rotor pitch position changed and maintains the constant head and speed. Necessary weights and spring balances are included to apply load on the break drum. Suitable cooling water arrangement for the break drum is provided. The speed of the turbine was measured by using Tachometer for the different loads.

A. Observations

The following observations noted down: Vane position, Speed N‟‟ RPM, Delivery pressure, P‟‟ N/mm2, Discharge „Q‟‟ LPS, Spring balance load m_s, Apply load M.

B. Calculation for Francis Turbine

The following formulas are involved in calculating all the parameters:

1. Total head

$$H = \frac{V^2}{2g} + z + \frac{p}{w}$$

Where, H = total head (ft)
v =absolute velocity of water (ft/s)
z = potential energy (ft)
p=intensity of pressure (lb/ft^2)
w = density of water (lb/ft^3)
g = acceleration of gravity (ft/s^2)

2. Water power

$$HP = \frac{qwH}{550}$$

Where, q = rate of discharge (ft^3/s)

3. Torque

$$T = \frac{D}{2}(T_1 - T_2)$$

Where, T = torque (lb-in)
D = diameter of brake drum (in)

4. Brake power (hp)

$$Bhp = \frac{2\pi NT}{33000 \text{ x } 12}$$

Where, N = speed in rpm

5. Efficiency

$$\eta = \frac{Bhp}{Water\ \ power}$$

Where, Bhp = brake power

6. Unit speed $N_u = \frac{N}{\sqrt{H}}$

Where, N_u = unit speed (rpm)

7. Unit quantity $q_u = \frac{q}{\sqrt{H}}$

8. Unit power

$$Bhp_u = \frac{Bhp}{H^{\frac{3}{2}}}$$

9. Specific speed

$$N_s = \frac{N\sqrt{Bhp}}{H^{\frac{5}{4}}}$$

IV. CHARACTERISTICS CURVES

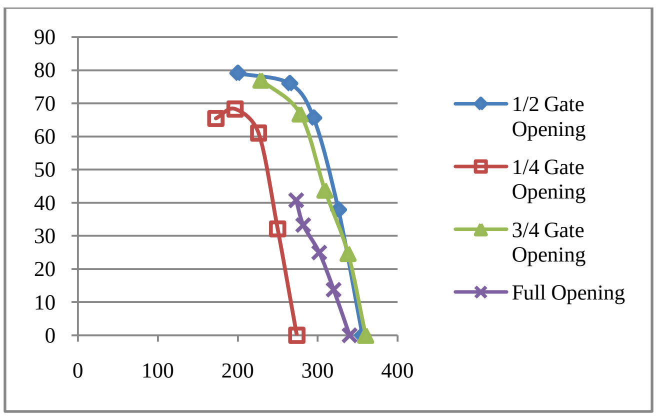

Fig. 3 Efficiency Vs Unit Speed at constant head 15 feet

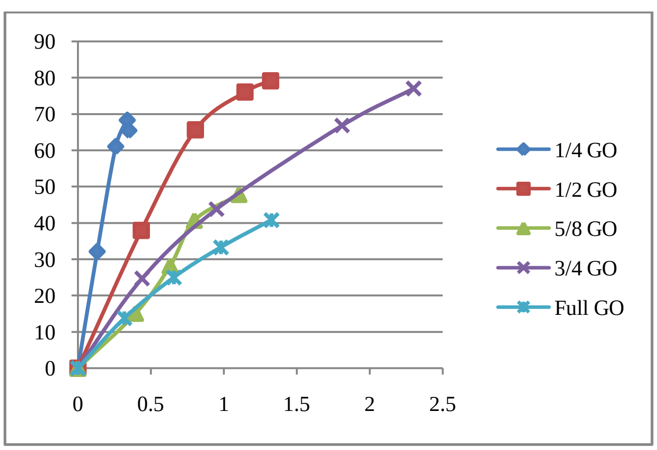

Fig. 4 Efficiency Vs Unit Power at constant head 15 feet

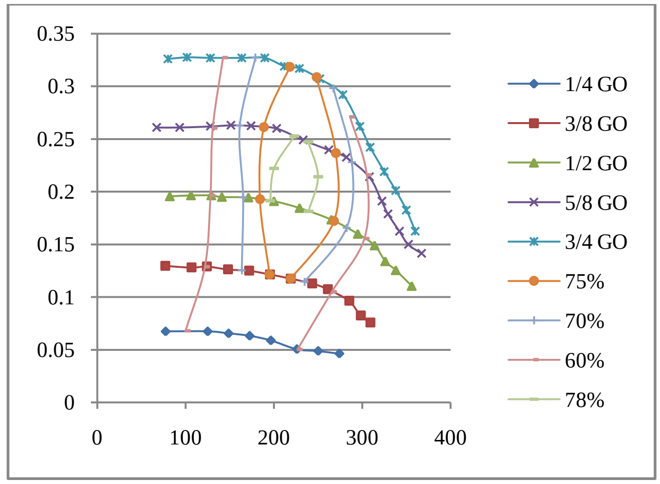

Fig. 5 Characteristic Curve for the turbine under the constant pressure head

V. RESULT TABLES

Table 1 Reading of Francis Turbine at Constant Head

Gate Opening	Discharge Cu.ft per sec	RPM	Brake Load(kg)		Net Load (kg)
			Slack (kg)	Tight (kg)	
1/4	0.1945	1150	0.00	0.00	0
	0.2050	1050	0.10	0.70	0.6
	0.2120	950	0.20	1.50	1.3
	0.2470	825	0.25	2.20	1.85
	0.2650	725	0.30	2.60	2.3
	0.2750	625	0.40	3.20	2.8
	0.2830	524	0.45	3.60	3.15
	0.2830	325	0.45	4.00	3.55
	0.2900	0	0.60	4.90	4.3

Gate Opening	Discharge Cu.ft per sec	RPM	Brake Load(kg)		Net Load(kg)
			Slack (kg)	Tight (kg)	
3/8	0.3180	1300	0.00	0.00	0.00
	0.3460	1250	0.05	0.50	0.45
	0.4060	1200	0.25	1.80	1.55
	0.4525	1100	0.40	2.90	2.5
	0.4770	1025	0.55	3.55	3.00
	0.4950	925	0.65	4.50	3.85
	0.5125	825	0.75	5.20	4.75
	0.5440	525	1.30	7.40	6.10
	0..5475	0	1.50	9.20	7.70

Gate Opening	Discharge Cu.ft per sec	RPM	Brake Load(kg)		Net Load (kg)
			Slack (kg)	Tight (kg)	
1/2	0.4660	1500	0.00	0.00	0
	0.5300	1425	0.15	1.15	1
	0.5650	1375	0.20	1.70	1.5
	0.6280	1325	0.25	2.20	1.95
	0.6775	1250	0.75	2.60	1.85
	0.7350	1125	0.75	4.20	3.45
	0.8125	850	1.70	9.10	7.4
	0.8333	600	1.95	10.6	8.73
	0.8375	550	2.00	11.00	9.00
	0.8200	0	2.55	13.6	11.05

Gate Opening	Discharge Cu.ft per sec	RPM	Brake Load(kg)		Net Load (kg)
			Slack (kg)	Tight (kg)	
5/8	0.5975	1550	0.00	0.00	0.00
	0.6360	1490	0.15	0.80	0.65
	0.7600	1400	0.45	2.60	2.15
	0.9150	1315	0.80	4.80	4.00
	1.030	1125	1.55	8.50	6.95
	1.075	1000	1.83	10.25	8.42
	1.120	875	2.10	12.0	9.9
	1.135	650	2.35	14.0	11.7
	1.147	400	2.60	15.4	12.8
	1.156	0	2.90	16.8	13.9

Gate Opening	Discharge Cu.ft per sec	RPM	Brake Load(kg)		Net Load (kg)
			Slack (kg)	Tight (kg)	
3/4	0.688	1525	0.00	0.00	0.000
	0.857	1440	0.25	1.70	1.450
	1.040	1330	0.7	4.10	3.400
	1.270	1210	1.60	8.75	7.150
	1.384	1000	2.25	13.20	10.95
	1.430	830	2.60	15.50	12.90
	1.430	715	2.70	16.40	13.70
	1.432	580	2.93	17.6	14.67
	1.434	445	3.15	18.80	15.60
	1.340	0	3.5	19.9	16.40

Gate Opening	Discharge Cu.ft per sec	RPM	Brake Load(kg)		Net Load (kg)
			Slack	Tight	
7/8	0.8200	1515	0.00	0.00	0.00
	0.9530	1440	0.20	1.20	1.00
	0.0870	1370	0.45	2.70	2.25
	1.2300	1300	0.80	4.60	3.80
	1.3350	1250	1.15	6.10	4.95
	1.4900	1140	2.00	10.7	8.70
	1.5700	1050	2.55	13.5	10.95

Gate Opening	Discharge Cu.ft per sec	RPM	Brake Load(kg)		Net Load
			Slack	Tight	
1	0.9600	1450	0.00	0.00	0
	1.1000	1380	0.30	1.40	1.1
	1.2350	1305	0.70	3.10	2.4
	1.3650	1230	1.10	4.90	3.8
	1.4900	1195	1.50	6.80	5.3
	1.5650	1150	1.85	8.50	6.65
	1.5700	1150	1.90	8.60	6.7

Table 2 Reading of Francis Turbine at Constant Head

Gate opening	Net Head	Unit Speed	Unit Discharge, Q(m^3/s)	Unit Power	Efficiency
1/4 opening	17.832	274.0	0.0463	0.000	0.000
	17.832	250.0	0.0488	0.132	32.10
	17.832	226.0	0.0505	0.259	61.00
	17.832	196.5	0.0588	0.338	68.25
	17.832	172.5	0.0632	0.349	65.40
	17.832	148.7	0.0655	0.366	66.00
	17.832	125.0	0.0674	0.347	61.10
	17.832	77.40	0.0674	0.243	60.25
	17.832	0.000	0.0690	0.000	0.000

Gate opening	Net Head	Unit Speed	Unit Discharge, Q(m^3/s)	Unit Power	Efficiency
3/8 opening	17.832	309.0	0.0758	0.000	0.000
	17.832	285.0	0.0964	0.390	47.75
	17.832	261.0	0.1074	0.577	63.00
	17.832	243.0	0.1130	0.645	67.50
	17.832	219.0	0.1175	0.747	74.7
	17.832	195.5	0.1215	0.770	74.50
	17.832	172	0.125	0.768	72.00
	17.832	148.0	0.1262	0.715	66.25
	17.832	124.4	0.1278	0.671	61.00

	17.832	106.5	0.1285	0.59	53.9
	17.832	77	0.1296	0.481	43.35
	17.832	0.000	0.1280	0.000	0.000

Gate opening	Net Head	Unit Speed	Unit Discharge, Q(m^3/s)	Unit Power	Efficiency
1/2 opening	17.832	356.0	0.1105	0.000	0.000
	17.832	338.0	0.1255	0.299	27.90
	17.832	326.0	0.1340	0.434	37.90
	17.832	314.0	0.1490	0.655	51.40
	17.832	295.0	0.1600	0.805	65.60
	17.832	265.0	0.1735	1.145	76.00
	17.832	229.0	0.1845	1.270	78.80
	17.832	200	0.1910	1.320	79.10
	17.832	171	0.1945	1.216	71.6
	17.832	141.0	0.1950	1.082	63.40
	17.832	129.0	0.1965	1.040	60.30
	17.832	106.0	0.1965	0.896	52.00
	17.832	82.00	0.1956	0.720	42.00
	17.832	0.000	0.1930	0.000	0.000

Gate opening	Net Head	Unit Speed	Unit Discharge, Q(m^3/s)	Unit Power	Efficiency
5/8 opening	17.832	367.0	0.1415	0.000	0.000
	17.832	342.0	0.1625	0.395	28.2
	17.832	329.0	0.1790	0.632	40.7
	17.832	308.0	0.2140	1.104	58.3
	17.832	282.0	0.2325	1.530	73.7
	17.832	262.0	0.2396	1.642	76.00
	17.832	233.0	0.2490	1.760	78.5
	17.832	203.0	0.2600	1.815	77.00
	17.832	174.0	0.2625	1.736	73.00
	17.832	151.0	0.2630	1.614	67.5
	17.832	128.0	0.26	1.43	59.0
	17.832	93.00	0.263	1.075	45.2
	17.832	67.00	0.261	0.809	34.1
	17.832	0.000	0.25	0.000	0.00

Gate opening	Net Head	Unit Speed	Unit Discharge, Q(m^3/s)	Unit Power	Efficiency
3/4 opening	17.832	360.0	0.1625	0.000	0.000
	17.832	338.0	0.2010	0.440	24.70
	17.832	309.0	0.2420	0.950	43.80
	17.832	297.0	0.2423	1.230	50.70
	17.832	278.0	0.2920	1.810	66.80
	17.832	252.0	0.3070	2.150	74.60
	17.832	229.0	0.3170	2.300	77.00
	17.832	212.0	0.3190	2.230	74.00
	17.832	189.7	0.327	2.250	72.50
	17.832	163.5	0.327	2.250	66.30
	17.832	128.0	0.327	1.730	55.70
	17.832	101.6	0.3275	1.460	47.20
	17.832	80.00	0.3260	1.160	37.10
	17.832	0.000	0.3080	0.000	0.000

Gate opening	Total head	Unit speed	Unit quantity Q(m^3/s)	B.h.p	efficiency
7/8	17.832	355	0.192	0.000	0.000
	17.832	337.0	0.223	0.302	15.3
	17.832	319.0	0.253	0.647	28.4
	17.832	300	0.284	1.937	39.6
	17.832	287	0.307	1.300	45.3
	17.832	259	0.339	2.080	63.8
	17.832	238	0.356	2.42	70.00

Gate opening	Total head	Unit speed	Unit quantity Q(m^3/s)	B.h.p	efficiency
Full Opening	17.832	340.0	0.225	0.000	0.000
	17.832	320.0	0.256	0.319	13.80
	17.832	302.0	0.286	0.657	25.00
	17.832	282.0	0.313	0.980	33.30
	17.832	273.0	0.340	1.326	40.80
	17.832	261.0	0.355	1.606	46.60
	17.832	261.0	0.356	1.620	46.80

The following table describes only to draw the performance characteristic curve in four different efficiencies and gate openings.

No.	78%		75%		70%		60%	
	Unit Speed	Unit Discharge	Unit Speed	Unit Discharge	Unit Speed	Unit Discharge	Unit Speed	Unit Discharge
1/4 GO	-	-	-	-	-	-	227	0.050
	-	-	-		-	-	120	0.068
3/8 GO	-	-	219	0.117	235	0.114	266	0.105
	-	-	195	0.121	164	0.125	122	0.129
1/2 GO	239	0.181	268	0.172	282	0.166	303	0.155
	196	0.191	184	0.193	165	0.195	128	0.196
5/8 GO	239	0.247	271	0.236	288	0.228	305	0.216
	223	0.253	189	0.261	161	0.263	130	0.260
3/4 GO	-	-	248	0.309	267	0.298	286	0.271
	-	-	218	0.318	179	0.327	142	0.327

VI. CONCLUSIONS

Experimental analysis was carried out to determine the main characteristics curve at part load conditions. It was done for constant pressure head 15 feet and different gate opening.For different loads, constant head and constant pressure are maintained. High efficiency cannot be obtained when a low discharge is flowing through the runner. This is because the runner blades in Francis Turbine are fixed and integral with hub.When the loads increase, the speed of turbine runner will be decrease but the discharge is increasing. This paper may be a few error because of testing with hanging every part load on brake drum. Brake loads applied to the brake drum, the speed of runner, the gate reading and discharge rate of the supply water is observed and the value of the supply head, power output, power supplied or water horsepower, unit speed, unit quantity and efficiencies are computed from those observed data for all runs. The runner blade designed is more efficiency and power output of constant pressure head 20 feet than that of 15 feet. In this paper experimental test ateach gate opening, it is seen thesame efficiencies in different speeds and discharges. This paper mentions characteristic curve and other observations for a only constant pressure head 15 feet. The following observations were made from speed on tachometer,spring balance reading, apply load reading, delivery pressure.This paper is also especially presented the various performance characteristics curves plottedfor 60%, 70%, 75%, 78% efficiencies and four different gate opening.

ACKNOWLEDGEMENT

The authors are thankful to Professor and Head of department of mechanical engineering, Yangon Technological University allowed to use in fluid mechanics laboratory. The authors are also greatly indebted Dr. KhinMaung Aye for his invaluable advice to do in Francis turbine research work at YTU.

REFERENCES

[1]. R.K. Rajput, "Fluid Mechanics and Hydraulic Machines", Laxmi Publications (P) Ltd. New Delhi (India).
[2]. R. K. Bansal," Fluid Mechanics and Hydraulic Machines", Laxmi Publications (P) Ltd. New Delhi (India).
[3]. D. S. Kumar," Fluid Mechanics and Hydraulic Machines", Laxmi Publications (P) Ltd. New Delhi (India).
[4]. Yunus A. Cengel and John M. Cimbala, "Fluid Mechanics Fundamentals and Applications" McGraw Hill.
[5]. D. S. Kumar, "Fluid Mechanics & Fluid Power Engineering" S.K. Kataria Publications.
[6]. C.P. Kothandaraman& R. Rudramoorthy" Basic Fluid Mechanics" New Age Publications.
[7]. J.F. Douglas, J.M. Gasiorek& J.A. Swaffieid, "Fluid Mechanics", ELBS Publications.
[8]. A. K. Mohanty, "Fluid Mechanics" Prentice Hall Publications.
[9]. A. K. Jain, "Fluid Mechanics", Khanna Publications.)
[10]. T. Teressa, G GVisal, P Sai Ram, M Srimani Kumar, Experimental Analysis on Francis Turbine at Full Load to Determine the Performance Characteristics Curves, International Journal of Mechanical Engineering and Technology9(2), 2018, pp. 663–669