THE EFFECT AMOUNT NOMINAL STEAM FLOW ON THE GAS BURNER DESIGN ELEMENTS FOR STEAM GENERATOR

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ABSTRACT

To help designers understand Important and influencing elements for choosing the suitable gas burner directly from the charts without resorting to complex mathematical operations and When studying many variables that affect the work of the gas burner of steam boilers in a set of different operating conditions and after selecting a burner that relies on natural gas as fuel, the results of the study and the mathematical processes are presented about the effect of the design of openings and the dimensions of injection tube and dependence on the amount of nominal steam flow to be produce.

KEYWORDS: Design Burner, Steam Generator, Nominal Steam Flow & Natural Gas

Received: Jun 05, 2020; **Accepted:** Jun 25, 2020; **Published:** Oct 05, 2020; **Paper Id.:** IJMPERDJUN20201475

INTRODUCTION

Burner an important part of the steam generator, its main function is to mix fuel and air in specific proportions to produce heat energy in a boiler furnace, The energy efficiency of a fuel burner depends on the type of fuel burned in the boiler because each type of fuel has different combustion properties. Gaseous fuel is usually the easiest to burn and control within a boiler. Liquid fuel is easy to handle and burn, while solid fuel is the most difficult [10]. Natural gas burns cleanly because it mixes with air easily and the products of combustion are water vapor and carbon dioxide, with small amounts of sulfur and nitrogen oxides. In general, complete combustion of natural gas can be achieved easily, and if the combustion equipment is well-maintained, in addition to making precise designs for the burner to obtain the largest amount of heat resulting from the combustion process and avoid heat loss and increase efficiency.[4,5]

MATHEMATICAL CALCULATION

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Equations and Data For Use

These values were chosen to design a steam boiler generator that produces a nominal steam flow [Dn] between (10 – 50) [T/h].

Table 1: Nominal Steam Flow

10	18	26	34	42	50
12	20	28	36	44	
14	22	30	38	46	
16	24	32	40	48	

Table 2: Operational Conditions

Sy.	Quantity	Value	Sy.	Quantity	Value
tn	nominal temperature of the steam	180 [°C]	d	humidity of furnace gas	18 [g/m ³ N]
pn	nominal pressure of the steam	10 [bar]	λ	coefficient for exhaust air	1.1 const.
t'e	temperature of supply water	60 [°C]	pref	reference pressure	760 [mmHg]
tev	temperature of the flue exhaust gas	220 [°C]	tref	reference temperature	0 [°C]
t _p	temperature of the preheated	220 [°C]	p	atmospheric pressure	1.013 [bar]
pe'	pressure of supply water	11 [bar]	pr	pressure in a manifold	4000 [mmH ₂ O]
to	temperature of the gas	25 [°C]	ρa	air density	1.293[kg/m ³ N]
X	air humidity	10 [g/kg]	ρg	density of natural gas	0.72 [kg/m ³ N]

P00ref, tref In ideal conditions, Nominal temperature and pressure:- the pressure and temperature of the superheated steam from a boiler, $p = 1.013 \text{ [bar]} \rightarrow 101300 \text{ [pa]}$, $p_r = 4000 \text{ [mm H}_2\text{O]} \rightarrow 39240 \text{ [pa]}$

Table 3: Analysis of natural gas

Volume Participation of the Element r _j :			Density	
CH ₄ ^{anh}	99.4 %		ρCH ₄ ^{anh}	0.717 kg/m ³ _N
C ₂ H ₂ ^{anh}	0.2 %		ρC ₂ H ₂ ^{anh}	1.162 kg/m ³ _N
H ₂ ^{anh}	0.2 %		ρH ₂ ^{anh}	0.0898 kg/m ³ _N
O ₂ ^{anh}	0.2 %		ρO ₂ ^{anh}	1.429 kg/m ³ _N
Average Specific Heat Capacity c _j at (t=0 °C and Const. p)			Calorific Power Q _i	
cCH ₄	1.549	kJ/m ³ .K	Q _i CH ₄ ^{anh}	35797 kJ/m ³
cC ₂ H ₂	1.87	kJ/m ³ .K	Q _i C ₂ H ₂ ^{anh}	56940 kJ/m ³
cH ₂	1.276	kJ/m ³ .K	Q _i H ₂ ^{anh}	10760 kJ/m ³
cO ₂	1.3059	kJ/m ³ .K	Q _i O ₂ ^{anh}	0 kJ/m ³
cH ₂ O	1.494	kJ/m ³ .K		

- Calorific power Q_i:- The amount of energy produced by the complete combustion of a material or fuel.
- Average specific heat capacity c_j:- the amount of heat required to raise the unit temperature of a unit mass of a body

Gas Pipe Diameter

The diameter of the gas conductor pipe to the burner D_i[m] increases with increasing amount of vapor to be produced, and we take the value D_i at D_n (12, 14, 16 [T/h]) equal to D_i at (20 [T/h]) because they are values very near etc.

$$D_i \text{ at } D_n (10 \text{ [t/h]}) = 0.2 \text{ m const.}$$

$$D_n (20 \text{ [T/h]}) = D_i \text{ at } (10 \text{ [T/h]}) \cdot \sqrt{2} = 0.282842712 \text{ [m]}$$

$$D_n (30 \text{ [T/h]}) = D_i \text{ at } (20 \text{ [T/h]}) \cdot \sqrt{2} = 0.4 \text{ [m]}$$

$$D_n (40[T/h]) = D_i \text{ at } (30[T/h]) \cdot \sqrt{2} = 0.565685425 \text{ [m]}$$

$$D_n (50 [T/h]) = D_i \text{ at } (40[T/h]) \cdot \sqrt{2} = 0.642 \text{ [m]}$$

Gas Heating Value Calculator [1]

$$f1 - 2 = \frac{100}{(100 + 0.1242 \cdot d)} \quad (1)$$

$$Q_i^{anh} = 0.01 \sum r_j \cdot Q_{i_j} \quad (2)$$

$$Q_i^{um} = f1 - 2 \cdot (Q_i^{anh} - 2.51 \cdot d) \quad (3)$$

Where (f1-2) factor to pass from the dry gas to the wet, (Q_i^{anh}) calorific power for dry gas [$\text{kJ}/\text{m}^3_{\text{N}}$], (Q_i^{um}) calorific power for moist gas [$\text{kJ}/\text{m}^3_{\text{N}}$].

Volumes of Air and Gases Combustion [1,10]

$$V_{o_{min}} = 0.01 \cdot [0.5 \cdot C_{O_2}^{anh} + 0.5 \cdot H_2^{anh} + 1.5 \cdot H_2S^{anh} + (\sum (m + \frac{n}{4}) \cdot C_m H_n^{anh}) - O_2^{anh}] \quad (4)$$

$$V^0_a = 100 \cdot \frac{V_{o_{min}}}{21} \quad (5)$$

$$V_{aum}^0 = (1 + 0.00161 \cdot x) \cdot V^0_a \quad (6)$$

$$V_{CO_2} = 0.01 \cdot (CO_2^{anh} + C_{O_2}^{anh} + \sum m \cdot C_m H_n^{anh}) \quad (7)$$

$$V_{SO_2} = 0.01 \cdot (SO_2^{anh} + H_2S^{anh}) \quad (8)$$

$$V_{RO_2} = V_{CO_2} + V_{SO_2} \quad (9)$$

$$V_{N_2}^0 = 0.79 \cdot V^0_a + 0.01 \cdot N_2^{anh} \quad (10)$$

$$V_{gu}^0 = V_{RO_2} + V_{N_2}^0 \quad (11)$$

$$V_{H_2O}^0 = 0.01 \cdot (H_2^{anh} + H_2S^{anh} + 0.5 \cdot \sum n \cdot C_m H_n^{anh} + 0.01242 \cdot d) + 0.00161 \cdot x \cdot V^0_a \quad (12)$$

$$V_g^0 = V_{gu}^0 + V_{H_2O}^0 \quad (13)$$

$$V_a = \lambda \cdot V^0_a \quad (14)$$

$$V_{aum} = \lambda \cdot V_{aum}^0 \quad (15)$$

$$C_c^{anh} = 0.01 \cdot \sum r_j \cdot c_j \quad (16)$$

$$C_c^{um} = f1 - 2 \cdot (C_c^{anh} + 1.242 \cdot 10^{-3} \cdot d \cdot c_{H_2O}) \quad (17)$$

- Use Table 2 and 3 to find value for Eq. (1, 2,...,17).
- (keep the above results in Table 4), This Table is important to find enthalpy theoretical of humid air, enthalpy of combustion gas at different temperature.

V^0_a , V_{aum}^0 , $V_{o_{min}}$ volume strictly necessary of dry air, moist air and oxygen [$\text{m}^3_{\text{N}}/\text{m}^3_{\text{N}}$].

V_a , V_{aum} actual volume of dry air and moist air [$\text{m}^3_{\text{N}}/\text{m}^3_{\text{N}}$]. V_{CO_2} , V_{SO_2} amount of carbon and sulfur dioxide

$[m^3_N/m^3_N]$. $V^0_g, V^0_{gu}, V^0_{H_2O}, V^0_{N_2}, V_{RO_2}$ theoretical volume of wet flue gas, dry flue gas, water vapor, nitrogen and gas Triatomic $[m^3_N/m^3_N]$.

$C_{c\text{ anh}}, C_{c\text{ um}}$ specific heat of anhydrous gas fuel and moist gas fuel $[KJ/m^3.K]$, (m^3_N) normal cubic meters.

Table 4: Flue Gas Enthalpy for Natural Gas

t	$V_{RO_2}=0.998$ $[m^3_N/m^3_N]$		$V^0_{N_2}=7.496$ $[m^3_N/m^3_N]$		$V^0_{H_2O}=2.145$ $[m^3_N/m^3_N]$		3+5 +7	I^0_g $[kJ/m^3_N]$	$V^0_{aum}=9.638$ $[m^3_N/m^3_N]$		I^0_{aum} $[kJ/m^3_N]$	$I_g(\lambda, t) = [I^0_g + (\lambda - 1) \cdot I^0_{aum}]$ $\lambda = 1.1$
°C	c_{CO_2}	$c_{CO_2} \cdot V_{RO_2}$	c_{N_2}	$c_{N_2} \cdot V^0_{N_2}$	c_{H_2O}	$c_{H_2O} \cdot V^0_{H_2O}$			c_{aum}	$c_{aum} \cdot V^0_{aum}$		
1	2	3	4	5	6	7	8	9 = 8 x 1	10	11	12 = 11 x 1	13
0	1.600	1.597	1.294	9.699	1.494	3.204	14.500	0.000	1.318	12.703	0.000	0.000
100	1.700	1.697	1.295	9.707	1.505	3.228	14.632	1463.166	1.324	12.761	1276.129	1590.779
200	1.787	1.784	1.299	9.737	1.522	3.264	14.785	2957.005	1.331	12.829	2565.751	3213.580
400	1.929	1.925	1.316	9.864	1.565	3.356	15.146	6058.397	1.354	13.050	5220.176	6580.415
600	2.041	2.037	1.340	10.044	1.614	3.462	15.543	9325.654	1.382	13.320	7992.190	10124.873
800	2.131	2.127	1.367	10.247	1.668	3.577	15.951	12760.621	1.411	13.600	10879.865	13848.607
1000	2.203	2.199	1.391	10.427	1.722	3.693	16.318	16318.344	1.437	13.850	13850.430	17703.387
1200	2.263	2.258	1.414	10.599	1.766	3.809	16.666	19999.729	1.461	14.082	16898.103	21689.539
1400	2.313	2.308	1.434	10.749	1.828	3.921	16.978	23768.893	1.483	14.294	20011.317	25770.024
1600	2.355	2.350	1.452	10.884	1.876	4.023	17.258	27612.106	1.501	14.467	23147.664	29926.872
1800	2.391	2.386	1.468	11.004	1.921	4.120	17.510	31517.888	1.517	14.622	26318.709	34149.759
2000	2.422	2.417	1.482	11.109	1.962	4.208	17.734	35467.499	1.532	14.766	29532.163	38420.715
2200	2.448	2.443	1.495	11.206	2.001	4.291	17.941	39469.257	1.546	14.901	32782.243	42747.482

Where (c_{aum}) specific average heat between (0 to t $^{\circ}C$) at constant humid air pressure in $[KJ/m^3_N.K]$, $(c_{CO_2}, c_{N_2}, c_{H_2O})$ specific heat at constant pressure of carbon, nitrogen, water vapor dioxide $[kJ/m^3_N.K]$.

I^0_g, I^0_{aum} theoretical enthalpy of combustion gas and humid air at(t $^{\circ}C$) $[kJ/m^3_N]$, I_g enthalpy of combustion gas $[kJ/m^3_N]$.

Can find all specific heat value of fuel gas and gas combustion from special tables for Combustion processes for natural gas fuel [1,8]. These mathematical relationships (1,2,317) relate to the quantities of air and flue gases in the combustion fuel when designing steam generators. These relationships change when the type of fuel used (solid or liquid) changes.

Convert the value Dn from $[T/h \text{ to } kg/s] = Dn \cdot (1000/3600)$

Table 5

Dn[T/h]	Dn[kg/s]	Dn[T/h]	Dn[kg/s]	Dn[T/h]	Dn[kg/s]	Dn[T/h]	Dn[kg/s]
10	2.778	22	6.111	34	9.444	46	12.778
12	3.333	24	6.667	36	10.000	48	13.333
14	3.889	26	7.222	38	10.556	50	13.889
16	4.444	28	7.778	40	11.111		
18	5.000	30	8.333	42	11.667		
20	5.556	32	8.889	44	12.222		

At p_n and t_n from steam / vapor table $i_n = 2777.44$ [KJ/kg]

At p_e^- and t_e^- from steam/ water table $i_e^- = 252.1$ [KJ/kg]

Where i_e^- , i_n specific enthalpy of water supply and steam coming out of the boiler [KJ/kg] [12], { steam tables: are defined as the thermodynamic data that contain the properties of water or steam from charts in [9]}.

Useful Heat for Every Dn

Useful heat exchanged in the steam generator between the flue gases and the working agent

$$Q_u = D_n \cdot (i_n - i_e^-) \quad (18)$$

Figure 1: Useful Heat Q_u [KW].

We note the linear relationship between the quantity steam produced by the boiler and the amount of useful real heat used for heating (useful heat exchanged in the steam generator between the resulting heat and received).

The η of a Generator

(efficiency output of a generator steam) can find by using value of (q_{ev} , q_{ch} , q_m , q_{ex} , q_{ef}) equation(19), we note the value of q_m and q_{ch} (heat loss for incomplete mechanical and chemical combustion) it depended on characteristics boiler combustion chamber, 1. For liquid and gaseous fuel with ash ($q_m = 0$) and ($q_{ch} = 0.5$ to gas natural and $q_{ch} = 1.5$ for another type of gas), 2. Solid fuel without ash q_m increase between (0.5 – 6) and ($q_{ch} = 0$) depended on type solid fuel. q_{rf} (heat Loss with residues from the furnace), Its value is very small, near zero, for q_{ex} (heat loss through walls outside) in Fig .11 we notice two curves depending on the boiler flow surface (1. Generator without heat exchange surfaces, 2. Generator with heat exchange surfaces), We use the second curve to find values q_{ex} for D_n between (10 - 50)[t/h], Value q_{ev} calculate from Eq. (21,22,17,23).

$$\eta = 100 - (q_{ev} + q_{ch} + q_m + q_{ex} + q_{ef}) \quad (19)$$

for gas natural ($q_m = q_{rf} = 0$), $q_{ch} = 0.5$ % constant.

$$q_{ev} [\%] = \frac{\left(\frac{Q_{ev}}{Q_{i_{um}}}\right)}{100} \quad (21)$$

$\lambda = 1.1$ from Table 4, Between ($I_g (200^\circ\text{C})$, $I_g (400^\circ\text{C})$) calculating I_g at $t_{ev} = 220^\circ\text{C}$.

Between ($I_{aum}^\circ (0^\circ\text{C})$, $I_{aum}^\circ (100^\circ\text{C})$) calculating I_{aum}° at $t_o = 25^\circ\text{C}$.

$$i_{co} = Cc^{um} \cdot t_o \quad (22)$$

$$Q_{ev} = \{I_g [\lambda_{ev}, t_{ev}] - \lambda_{ev} \cdot I_{aum} [t_o]\} - i_{co} \quad (23)$$

To find q_{ev} (heat loss with exhaust gas) use Eq.(3, 21,22,23) where (Q_{ev}) the heat loss [kJ/m^3_N], (i_{co}) specific enthalpy of fuel at ambient temperature[kJ/m^3_N], q_{ex} from fig. 11 find every η (D_n) [%] see table 5.

Table 5: Value of Heat loss Through Walls Outside (q_{ex}) and Efficiency Boiler					
$D_n[T/h]$	q_{ex}	[%] η	$D_n[T/h]$	q_{ex}	[%] η
10	1.7	88.741741	30	1.22	89.221741
12	1.6	88.841741	32	1.2	89.241741
14	1.5	88.941741	34	1.2	89.241741
16	1.4	89.041741	36	1.1	89.341741
18	1.3	89.141741	38	1	89.441741
20	1.28	89.161741	40	1	89.441741
22	1.27	89.171741	42	0.98	89.461741
24	1.26	89.181741	44	0.96	89.481741
26	1.25	89.191741	46	0.94	89.501741
28	1.24	89.201741	48	0.92	89.521741
50			0.9		89.541741

Nominal Flow of Natural Gas

We find nominal flow of natural gas B_g [m^3_N/s] by using Eq.(18, 19, 2, 3, 24) see figure2.

$$B_g(D_n) = \frac{Q_u(D_n)}{0.01 \cdot \eta(D_n) \cdot Q_{i_{um}}} \quad (24)$$

Figure 2: Nominal Flow of Natural Gas B_g [m^3_N/s].

In this graph, it shows the true relationship between the increase in the amount of gas used for the combustion and

heating process and the steam production.

Air Flow Circulated in the Burner

By use Eq. (4, 5, 6, 24, 25), coefficient for exhaust air λ and temperature of the preheated air T_p in kelvin.

$$Da = \lambda \cdot V_{aum}^0 \cdot Bg(Dn) \cdot \left(\frac{T_p}{273}\right) \quad (25)$$

Figure 3: Air Flow Circulated in the Burner $Da[m^3N/s]$.

To increase the amount of heat produced during the combustion process, the amount of air entering the burner must be increased, along with an increase in the amount of gas for the occurrence of perfect combustion.

The Air Flow Nozzle

Required average air flow rate $wa = 20$ [m/s][14], It is constant value and use Eq. (25, 26, 27) we find cylindrical cross section and diameter see figure.14.

$$Sa = \frac{Da}{wa} \quad (26)$$

Figure 4: Cylindrical Cross Section $Sa[m^2]$.

The area of the air transporter tube (the air flow nozzle) increases with the increase in the amount of steam produced to maintaining the stability of the burner flame and the stable distribution of heat.

$$da [m] = \frac{\sqrt{4}}{\pi} * Sa \quad (27)$$

Figure 5: Diameter of Cross-Section da [m].The Diameter Increases with Increasing Area.

The Outer Diameter of the Swirl Register

By use Eq. (26, 27, 28, 29) and you should find γ (considered pallets by angle at the center) it depend on number of the blades (nb) and the tilt angle of the blades (θ).we have two value of (γ , D) if $\theta = 30^\circ$ $nb=18$ and $\theta = 45^\circ$, $nb = 24$ see figure 15

$$\gamma = \frac{360}{nb} \quad (28)$$

$$D = da \frac{\cos \theta}{\cos(\theta + 0.7\gamma)} \quad (29)$$

Figure 6: Outer Diameter of the Swirl Register D [mm].

The increase in the diameter of the circle in relation to the tilt angle of the blades o in order to avoid occurrence pressure drop in flow gas inlet to the burner .

The Thickness between the Blades

$$\varepsilon = da * \sin \frac{180}{nb} \cdot \sin \left(\theta + \frac{180}{nb} \right) - \delta \quad (30)$$

Where $\delta = 3$ mm Correction coefficient

Figure 7: The Thickness between the Blades ε [mm].

Working Length of the Blade

$$L = 1.6 \cdot \frac{d^2 a}{np \cdot \varepsilon} \cdot \cos \theta \quad (31)$$

Figure 8: Working Length of the Blade L [mm].

The Length of the Housing Air

$$L_c = L \cdot l_t \quad (32)$$

Where $l_t = 0.25$ [mm] constant (the length of the burning neck).

Figure 9: Working Length of the Blade L_c [mm].

The Maximum Diameter of the Housing Air

$$De = \frac{0,785 \cdot da^2}{Lc} + D \quad (33)$$

Figure 10: Maximum Diameter of the Housing De [mm].

We learned how to find the values for {Qu [KW], The η of a generator, Bg [m³N/s], Da [m³N/s] and da [mm]}. We can use these values to choose the appropriate type and size of the burner for the boiler, and this requires time and effort and affects the speed of work and production. So depending on the amount of steam to be produced (boiler capacity Dn[T/h]) and without resorting to using a mathematical equation, we have graphs that can extract all the values needed for the design directly [3].

Figure 11: Determination of the Percentage Heat Loss Outside [1].

1. Generator without Heat Exchange Surfaces, 2. Generator with Heat Exchange Surfaces.

Figure 12: High Pressure Gas Burner. [3].

Figure 14: Cross Section of a Blades[15] Figure 13: An Internal Section of a Kind Gas Burner[14].

CONCLUSIONS

For a certain size of fuel gas, they should have a high consumption rate. High consumption means less manufacturing costs and allows the heat to be produced which is usually most efficient. So to maintain the ratio of air/gas mixing inside the burner[13], the transmission piping diameters should not be kept too large for the flame spread speed to exceed the speed of the mixing process, and the flowing mixture speed should not be too high so that the complete combustion process does not take place and maintain the speed of entry of air and gas flow. The flame of the burner must be uniform in height and uniformly distributed inside the furnace. Control the internal gas and air velocity to make the mixing process homogeneous to avoid an explosion.[6,7]

ACKNOWLEDGMENTS

I would like to thank my supervisor {Prof. Dr. Ing. Ionel Gh. Pișă}. Head of the Thermal Equipment Department of the Polytechnic University of Bucharest / Faculty of Mechanical and Mechatronics Engineering for continuous follow-up, scientific guidance and assistance in giving accurate feedback.

REFERENCES

1. Pișă, I. (2013). *Generatoare de abur*. Politehnica Press.
2. Platvoet, E., & Baukal, C. (2013). *Process burners 101*. *Chemical Engineering Progress*, 109(8), 35-39.
3. C.I.B. UNIGAS S.p.A *Industrial burners Liquid catalog and price list*. URL: <http://www.cibunigas.com/ru/product-catalogs> [in Russian].
4. Zimont, V., Moreu, V., Battaglia, V., & Modi, R. (2011). *RANS and LES Modeling of the GE10 Burner*. *Energy and Power engineering*, 3(05), 607.
5. Eiseman, J. H., Weaver, E. R., & Smith, F. A. (1932). *Method for Determining the Most Favorable Design of Gas Burners*. *Bureau of Standards Journal of Research*, 8.
6. Gattei, L. (2009). *A study on the fluid dynamics of domestic Gas burners* (Doctoral dissertation, alma).
7. Berry, W. M., Brumbaugh, I. V., Moulton, G. F., & Shawn, G. B. (1921). *Design of atmospheric gas burners* (No. 193-202). US Government Printing Office.
8. Riello S.p.A., "Technical Handbook of the RG1 Burner," Via degli Alpini, 1-37045 Legnago (VR) Italia, 2001.
9. Meyers, C. H., Cragoe, C. S., & Mueller, E. F. (1947). *Table and Mollier chart of the thermodynamic properties of 1, 3-*

- butadiene. *J ResNatlBur Stand*, 39, 507-507.
10. Reitz, R. D., Ogawa, H., Payri, R., Fansler, T., Kokjohn, S., Moriyoshi, Y., ... & Boulouchos, K. (2020). *IJER editorial: The future of the internal combustion engine*.
 11. Noor, M. M., Wandel, A. P., & Yusaf, T. (2013). *Design and development of mild combustion burner. Journal of Mechanical Engineering and Sciences*, 5, 662.
 12. Denev, J. A., Dinkov, I., & Bockhorn, H. (2017). *Burner design for an industrial furnace for thermal post-combustion. Energy Procedia*, 120, 484-491.
 13. Gattei, L. (2009). *A study on the fluid dynamics of domestic Gas burners (Doctoral dissertation, alma)*.
 14. Good, M., & Sense, E. (2019). *High-Efficiency Gas Burners*.
 15. Mao, C. P., & Short, J. E. (2014). *U.S. Patent No. 8,800,146. Washington, DC: U.S. Patent and Trademark Office*.