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Pathway Transform Associated with H-Function and General Class of Polynomials

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Abstract—The object of this paper is to obtain Ƥ-transforms or Pathway transform of Fox's H-function and a general class of polynomials. Ƥ-transforms are useful in reaction rate theory in astrophysics. Pathway transform is generalization of many integral transforms, H-function and general class of polynomials are general in nature. These results provide a number of new and known results on specializing of the parameters. Some particular cases are mentioned also.

***Key words*—P-transform, Fox's H-function, General class of polynomials, Hermite polynomial, Laguerre polynomial.**

I. INTRODUCTION

The Ƥ-transform or pathway transform is defined and represented in Kumar and Kilbas[11] as

$$\left(P_{\vartheta}^{\rho,\alpha,\beta}f\right)(x) = \int_0^\infty D_{\rho,\alpha}^{\vartheta,\beta}(xt)\, f(t)\, dt \ , \ x > 0 \qquad (1.1)$$

where $D_{\rho,\alpha}^{\vartheta,\beta}(x)$ represents the kernel-function

$$D_{\rho,\alpha}^{\vartheta,\beta}(x)=\int_0^{\left[\frac{1}{a(1-\beta)}\right]^{\frac{1}{\rho}}} y^{\vartheta-1}\left[1-a\left(1-\beta\right)y^{\rho}\right]^{\frac{1}{1-\beta}} e^{-xy^{-\alpha}}\, dy \ , \ x > 0, \qquad (1.2)$$

With $\vartheta \in \mathbb{C}$, $\alpha > 0$, $\rho > 0$, $a > 0$, $\beta < 1$. When $D_{\rho,\alpha}^{\vartheta,\beta}(x)$ is given by (1.2), Ƥ-transform is called type-1 Ƥ-transform. If we use

$$D_{\rho,\alpha}^{\vartheta,\beta}(x)=\int_0^\infty y^{\vartheta-1}\left[1+a\left(\beta-1\right)y^{\rho}\right]^{-\frac{1}{\beta-1}} e^{-xy^{-\alpha}}\, dy\ , \ x > 0, \qquad (1.3)$$

For $\vartheta\in \mathbb{C}$, $\alpha>0$, $\rho>R$, $a>0$, $\beta>1$ in (1.1) then we obtain a type-2 Ƥ-transform. The Ƥ-transform of both types are defined in the space $L_{\vartheta,r}(0,\infty)$ consisting of the Lebesgue measurable complex valued functions f for which

$$\|f\|_{\vartheta,r}= \left\{\int_0^\infty \left|t^{\vartheta} f(t)\right|^r \frac{dt}{t}\right\}^{\frac{1}{r}} < \infty, \qquad (1.4)$$

For $1\leq r < \infty$, $\vartheta \in \mathbb{R}$. The Ƥ-transform of both the types are obtained by using the pathway model of Mathai [5], Mathai and Haubold [6]. If $\alpha=1$, $a=1$, and $\beta\rightarrow 1$, we have

$$\lim_{\beta\rightarrow 1} D_{\rho,1}^{\vartheta,\beta}(x) = Z_{\rho}^{\vartheta}(x) \ . \qquad (1.5)$$

Where $Z_{\rho}^{\vartheta}(x)$ is the kernel function of the Krätzel transform, introduced by Krätzel[12] and given by

$$K_{\vartheta}^{(\rho)} f(x) = \int_0^\infty Z_{\rho}^{\vartheta}(xt)\, f(t)\, dt, \ x> 0, \qquad (1.6)$$

Where $Z_{\rho}^{\vartheta}(x) = \int_0^\infty y^{\vartheta-1}\, e^{-y^{\rho}-xy^{-1}}\, dy$. (1.7)

The transform in (1.6) and its several modifications were considered by many authors. Glaeske et al. [14] considered a generalized version of the Krätzel transform and its compositions with fractional calculus operators

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on the spaces of $F_{p,\mu}$ and $F'_{p,\mu}$. Bonilla et al. [7,8] studied the Krätzel transform in the spaces $F_{p,\mu}$ and $F'_{p,\mu}$. Kilbas et al. [2] obtained the asymptotic representation for the modified Krätzel function. Kilbas et al. [3] studied the Krätzel function in (1.7) for all values of ρ and established it in terms of Fox's H-function. When $\alpha=1, a=1, \rho=1$ and $\beta\to1$, $\mathcal{P}$-transform of both types reduces to the Meijer transform. For $\alpha=1, a=1, \rho=1$ and $\beta\to1$ along with x replaced by $\frac{t^2}{4}$ in (1.2) and (1.3), we get

$$\lim_{\beta\to1} D_{1,1}^{\theta,\beta}\left(\frac{t^2}{4}\right)=2\left(\frac{t}{2}\right)^{\theta}K_{-\theta}(t), \tag{1.8}$$

Where $K_{-\theta}(t)$ is modified Bessel function of the third kind or the Mc-Donald function (see[4], sect. 7.2.2). Kilbas and Kumar [1] considered (1.3) for $\alpha=1$ and established its composition with fractional operators and represented it in terms of various generalized special functions.

The H- function introduced by Fox [10] will be represented and defined as follows

$$H_{p,q}^{m,n}\left[x\left|\begin{matrix}(a_j,\ A_j)_{1,p}\\(b_j,\ B_j)_{1,q}\end{matrix}\right.\right]=\frac{1}{2\pi i}\int_L \theta(\xi)\,x^{\xi}\,d\xi, \tag{1.9}$$

where

$$\theta(\xi)=\frac{\prod_{j=1}^{m}\Gamma(b_j-B_j\xi)\prod_{j=1}^{n}\Gamma(1-a_j+A_j\xi)}{\prod_{j=m+1}^{q}\Gamma(1-b_j+B_j\xi)\prod_{j=n+1}^{p}\Gamma(a_j-A_j\xi)}, \tag{1.10}$$

$i=\sqrt{-1}$, an empty product is interpreted as unity; $0\le m\le q$; $0\le n\le p$; $A_j(j=1,\dots,p)$ and $B_j(j=1,\dots,q)$ are positive numbers. L is a suitable contour of Barnes type such that the poles of $\Gamma(b_j-B_j\xi)(j=1,\dots,m)$ lie to the right of it and those of $\Gamma(1-a_j+A_j\xi)(j=1,\dots,n)$ lie to the left to it. Asymptotic expansions and analytic continuations of the H-function have been discussed by Braaksma[9]. A detailed account of the H-function is available in Srivastava et al. [16].

The general class of polynomials defined by Srivastava [15] in the following way

$$S_v^u[x]=\sum_{k=0}^{[v/u]}\frac{(-v)_{uk}}{k!}A_{v,k}x^k, \tag{1.11}$$

Where u, v are arbitrary positive integers and the coefficients $A_{v,k}(v,k\ge0)$ are arbitrary constants, real or complex.

II. MAIN RESULTS

Theorem1. If $f\in L_{\theta,r}(0,\infty)$, $z_1, z_2, \theta\in C$, $\alpha>0, b>0, h>0, \beta<1$ be such that $\rho>0$ in the case of a type-1 $\mathcal{P}$-transform then

$$P_{\theta}^{\rho,\alpha,\beta}\left[H_{p,q}^{m,n}(z_1t^b)S_v^u[z_2t^h]\right]=\sum_{k=0}^{[v/u]}\frac{(-v)_{uk}}{k!}A_{v,k}z_2^{k}\frac{1}{\rho\, x^{hk+1}}\frac{1}{[a(1-\beta)]^{\frac{\theta+\alpha+\alpha hk}{\rho}}}\Gamma\left(\frac{1}{1-\beta}+1\right)$$

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$$H^{m,n+2}_{p+2,q+1}\left[\frac{z_1 x^{-b}}{[a(1-\beta)]^{\frac{\alpha b}{\rho}}}\middle|\begin{matrix}(a_j,A_j)_{1,n},\ -hk,b,\ \left(1-\frac{\theta+\alpha+\alpha hk}{\rho},\frac{\alpha b}{\rho}\right),\ (a_j,A_j)_{n+1,p}\\ (b_j,B_j)_{1,q},\ \left(\frac{1}{\beta-1}-\frac{\theta+\alpha+\alpha hk}{\rho},\frac{\alpha b}{\rho}\right)\end{matrix}\right], \quad (2.1)$$

Where $\mathbb{R}\left(\frac{1}{1-\beta}+1\right)>0$ and the coefficients $A_{v,k}(v,k>0)$ are arbitrary constants, real or complex.

Theorem2. If $f\in L_{\theta,r}(0,\infty)$, $z_1, z_2, \theta\in C$, $\alpha>0$, $b>0$, $h>0$, $\beta>1$ be such that $\rho\in R$, $\rho\neq 0$ in the case of a type-2 Ƥ-transform then

$$Ƥ^{\rho,\alpha,\beta}_{\theta}\left[H^{m,n}_{p,q}(z_1t^b)S^u_v[z_2t^h]\right]$$

=

$$\sum_{k=0}^{[v/u]}\frac{(-v)_{uk}}{k!}A_{v,k}z_2^k\frac{1}{\rho x^{hk+1}}\frac{1}{[a(\beta-1)]^{\frac{\theta+\alpha+\alpha hk}{\rho}}}\frac{1}{\Gamma\left(\frac{1}{\beta-1}\right)}H^{m+1,n+2}_{p+2,q+1}\left[\frac{z_1x^{-b}}{[a(\beta-1)]^{\frac{\alpha b}{\rho}}}\middle|\begin{matrix}(a_j,A_j)_{1,n},\ (-hk,b),\ \left(1-\frac{\theta+\alpha+\alpha hk}{\rho},\frac{\alpha b}{\rho}\right),\ (a_j,A_j)_{n+1,p}\\ (b_j,B_j)_{1,m},\ \left(\frac{1}{\beta-1}-\frac{\theta+\alpha+\alpha hk}{\rho},\frac{\alpha b}{\rho}\right),(b_j,B_j)_{m+1,q}\end{matrix}\right]$$

, (2.2)

Where $\mathbb{R}\left(\frac{1}{\beta-1}\right)>0$ and the coefficients $A_{v,k}(v,k>0)$ are arbitrary constants, real or complex.

Proof. To obtain (2.1) we consider type-1 Ƥ-transform using (1.1) express Fox's H-function and general class of polynomial with the help of (1.9),(1.11), we have

$$Ƥ^{\rho,\alpha,\beta}_{\theta}\left[H^{m,n}_{p,q}(z_1t^b)S^u_v[z_2t^h]\right]=\int_0^\infty D^{\theta,\beta}_{\rho,\alpha}(xt)H^{m,n}_{p,q}(z_1t^b)\,S^u_v[z_2t^h]\,dt$$

$$=\frac{1}{2\pi i}\int_0^\infty\int_0^{\left[\frac{1}{a(1-\beta)}\right]^{\frac{1}{\rho}}} y^{\theta-1}\left[1-a(1-\beta)y^{\rho}\right]^{\frac{1}{1-\beta}}e^{-xty^{-\alpha}}$$

$$\int_L \theta(\xi)z_1^{\xi}t^{b\xi+hk}\,d\xi\sum_{k=0}^{[v/u]}\frac{(-v)_{uk}}{k!}A_{v,k}z_2^k\,dydt.$$

Changing the order of integrations and series, we get

$$=\sum_{k=0}^{[v/u]}\frac{(-v)_{uk}}{k!}A_{v,k}z_2^k$$

$$\frac{1}{2\pi i}\int_L \theta(\xi)z_1^{\xi}\int_0^{\left[\frac{1}{a(1-\beta)}\right]^{\frac{1}{\rho}}} y^{\theta-1}\left[1-a(1-\beta)y^{\rho}\right]^{\frac{1}{1-\beta}}\int_0^\infty e^{-xty^{-\alpha}}t^{b\xi+hk}\,dt\,dy\,d\xi\,.$$

Taking $xty^{-\alpha}=w$ and using gamma function, we obtain

$$=\sum_{k=0}^{[v/u]}\frac{(-v)_{uk}}{k!}A_{v,k}z_2^k$$

$$\frac{1}{2\pi i}\int_L \theta(\xi)\frac{z_1^{\xi}}{x^{b\xi+hk+1}}\Gamma(b\xi+hk+1)\int_0^{\left[\frac{1}{a(1-\beta)}\right]^{\frac{1}{\rho}}} y^{\theta+\alpha b\xi+\alpha hk+\alpha-1}\left[1-a(1-\beta)y^{\rho}\right]^{\frac{1}{1-\beta}}dy\,d\xi\,.$$

Now, solving inner integral with the help of beta function and then reinterpreting the result Mellin-Barnes contour integral in terms of Fox's H-function, we get the desired result.

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On the similar lines, the proof of result (2.2) can be established using the definition of H-function(1.9) and type-2 Ƥ-transform(1.1).

III. SPECIAL CASES

On taking a = 1, $\alpha=1$ and $\beta\to1$ in result (2.1), we have

(a)
$$\lim_{\beta\to1} P_\theta^{\rho,1,\beta}\left[H_{p,q}^{m,n}(z_1t^b)S_v^u[z_2t^h]\right]=\sum_{k=0}^{[v/u]}\frac{(-v)_{uk}}{k!}A_{v,k}z_2^{\,k}$$
$$\frac{1}{\rho x^{hk+1}}H_{p+2,q}^{m,n+2}\left[\frac{z_1}{x^b}\left|\begin{matrix}(a_j,A_j)_{1,n},\ (-hk,b),\left(1-\frac{\theta+hk+1}{\rho},\frac{b}{\rho}\right),\ (a_j,A_j)_{n+1,p}\\ (b_j,B_j)_{1,q}\end{matrix}\right.\right]. \quad (3.1)$$

By applying u = 2 in (2.1), (2.2) and (3.1), general class of polynomial reduces to Hermite polynomials [13] by setting

$S_v^u[x] = x^{v/2}H_v\left(\frac{1}{2\sqrt{x}}\right)$,in this case $A_{v,k}=(-1)^k$, we get

(b)
$$Ƥ_\theta^{\rho,\alpha,\beta}\left[H_{p,q}^{m,n}(z_1t^b)(z_2t^h)^{v/2}H_v\left(\frac{1}{2\sqrt{z_2t^h}}\right)\right]=\sum_{k=0}^{[v/2]}\frac{(-v)_{2k}}{k!}(-z_2)^k\frac{1}{\rho x^{hk+1}}\frac{1}{[a(1-\beta)]^{\frac{\theta+\alpha+\alpha hk}{\rho}}}$$
$$\Gamma\left(\frac{1}{1-\beta}+1\right)H_{p+2,q+1}^{m,n+2}\left[\frac{z_1x^{-b}}{[a(1-\beta)]^{\frac{\alpha b}{\rho}}}\left|\begin{matrix}(a_j,A_j)_{1,n},\ (-hk,b),\ \left(1-\frac{\theta+\alpha+\alpha hk}{\rho},\frac{\alpha b}{\rho}\right),\ (a_j,A_j)_{n+1,p}\\ (b_j,B_j)_{1,q},\ \left(\frac{1}{\beta-1}-\frac{\theta+\alpha+\alpha hk}{\rho},\frac{\alpha b}{\rho}\right)\end{matrix}\right.\right].(3.2)$$

(c)
$$Ƥ_\theta^{\rho,\alpha,\beta}\left[H_{p,q}^{m,n}(z_1t^b)(z_2t^h)^{v/2}H_v\left(\frac{1}{2\sqrt{z_2t^h}}\right)\right]=\sum_{k=0}^{[v/2]}\frac{(-v)_{2k}}{k!}(-z_2)^k\frac{1}{\rho x^{hk+1}}\frac{1}{[a(\beta-1)]^{\frac{\theta+\alpha+\alpha hk}{\rho}}}\frac{1}{\Gamma\left(\frac{1}{\beta-1}\right)}$$
$$H_{p+2,q+1}^{m+1,n+2}\left[\frac{z_1x^{-b}}{[a(\beta-1)]^{\frac{\alpha b}{\rho}}}\left|\begin{matrix}(a_j,A_j)_{1,n},\ (-hk,b),\ \left(1-\frac{\theta+\alpha+\alpha hk}{\rho},\frac{\alpha b}{\rho}\right),\ (a_j,A_j)_{n+1,p}\\ (b_j,B_j)_{1,m},\ \left(\frac{1}{\beta-1}-\frac{\theta+\alpha+\alpha hk}{\rho},\frac{\alpha b}{\rho}\right),(b_j,B_j)_{m+1,q}\end{matrix}\right.\right].(3.3)$$

(d)
$$\lim_{\beta\to1}Ƥ_\theta^{\rho,1,\beta}\left[H_{p,q}^{m,n}(z_1t^b)(z_2t^h)^{v/2}H_v\left(\frac{1}{2\sqrt{z_2t^h}}\right)\right]=\sum_{k=0}^{[v/2]}\frac{(-v)_{2k}}{k!}(-z_2)^k$$
$$\frac{1}{\rho x^{hk+1}}H_{p+2,q}^{m,n+2}\left[\frac{z_1}{x^b}\left|\begin{matrix}(a_j,A_j)_{1,n},\ (-hk,b),\left(1-\frac{\theta+hk+1}{\rho},\frac{b}{\rho}\right),\ (a_j,A_j)_{n+1,p}\\ (b_j,B_j)_{1,q}\end{matrix}\right.\right]. \quad (3.4)$$

Results in (b), (c) and (d) are valid under the same conditions as are required for (2.1), (2.2) and (3.1) respectively. Putting u = 1 in (2.1), (2.2) and (3.1) general class of polynomial reduces to Laguerre polynomials [13] by setting

$S_v^u[x]=L_v^s(x)$, in this case $A_{v,k}=\binom{v+s}{v}\frac{1}{(s+1)_k}$, we get

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(e) $P_{\theta}^{\rho,\alpha,\beta}\left[H_{p,q}^{m,n}\left(z_1 t^b\right) L_v^s\left(z_2 t^h\right)\right] =$

$$\sum_{k=0}^{[v]} \binom{v+s}{v-k} \frac{(-z_2)^k}{k!} \frac{1}{\rho\, x^{hk+1}} \frac{1}{[a(1-\beta)]^{\frac{\theta+\alpha+\alpha h k}{\rho}}} \Gamma\left(\frac{1}{1-\beta}+1\right) H_{p+2,q+1}^{m,n+2}\left[\frac{z_1 x^{-b}}{[a(1-\beta)]^{\frac{\alpha b}{\rho}}}\middle| \begin{matrix} (a_j,A_j)_{1,n},\ (-hk,b),\ \left(1-\frac{\theta+\alpha+\alpha h k}{\rho},\frac{\alpha b}{\rho}\right),\ (a_j,A_j)_{n+1,p} \\ (b_j,B_j)_{1,q},\ \left(\frac{1}{\beta-1}-\frac{\theta+\alpha+\alpha h k}{\rho},\frac{\alpha b}{\rho}\right) \end{matrix}\right]. \quad (3.5)$$

(f) $$P_{\theta}^{\rho,\alpha,\beta}\left[H_{p,q}^{m,n}\left(z_1 t^b\right) L_v^s\left(z_2 t^h\right)\right] = \sum_{k=0}^{[v]} \binom{v+s}{v-k} \frac{(-z_2)^k}{k!} \frac{1}{\rho\, x^{hk+1}} \frac{1}{[a(\beta-1)]^{\frac{\theta+\alpha+\alpha h k}{\rho}}} \frac{1}{\Gamma\left(\frac{1}{\beta-1}\right)}$$

$$H_{p+2,q+1}^{m+1,n+2}\left[\frac{z_1 x^{-b}}{[a(\beta-1)]^{\frac{\alpha b}{\rho}}}\middle| \begin{matrix} (a_j,A_j)_{1,n},\ (-hk,b),\ \left(1-\frac{\theta+\alpha+\alpha h k}{\rho},\frac{\alpha b}{\rho}\right),\ (a_j,A_j)_{n+1,p} \\ (b_j,B_j)_{1,m},\ \left(\frac{1}{\beta-1}-\frac{\theta+\alpha+\alpha h k}{\rho},\frac{\alpha b}{\rho}\right),\ (b_j,B_j)_{m+1,q} \end{matrix}\right]. \quad (3.6)$$

(g) $$\lim_{\beta\to 1} P_{\theta}^{\rho,1,\beta}\left[H_{p,q}^{m,n}\left(z_1 t^b\right) L_v^s\left(z_2 t^h\right)\right] = \sum_{k=0}^{[v]} \binom{v+s}{v-k} \frac{(-z_2)^k}{k!}$$

$$\frac{1}{\rho x^{hk+1}} H_{p+2,q}^{m,n+2}\left[\frac{z_1}{x^b}\middle| \begin{matrix} (a_j,A_j)_{1,n},\ (-hk,b),\ \left(1-\frac{\theta+hk+1}{\rho},\frac{b}{\rho}\right),\ (a_j,A_j)_{n+1,p} \\ (b_j,B_j)_{1,q} \end{matrix}\right]. \quad (3.7)$$

Results in(e), (f) and (g) are valid under the same conditions as are required for (2.1), (2.2) and (3.1) respectively. The results derived in this paper would at once yield a very large number of results, involving a large variety of polynomials and various special functions.

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