

Kunyima Relations Establishment On SS Sickle Cell Anaemia Women Investigation In Democratic Republic of Congo

ABSTRACT

Background: The sickle cell anaemia is a genetics sickness, autosomal, recessive, secondary to a punctual mutation at sixth codon level of β globine gene with substitution of glutamic acid by valine. The prevalence of S hemoglobin is relatively high, reaching 40 % of central Africa population.

Aim and objective: The overall purpose of this paper is to show that the cardiac exergetic yield depends only on differential pressure while $\dot{E}_v^+$ is greatly depending on cardiac frequency.

Methodology: The sickle cell anaemia persons were the target population. The experiments have been performed in Centre of Mixte Medicine and SS anaemia in Kinshasa (DRC) called Centre MABANGA. The blood pressure measurements and calculations are our methodology of work. The calculations have been done individually on the sample of 82 females whose the age varies between 13-57 years. The figures have been plotted by means of Origin 8 program. The Visio 2010 software was used for equations.

Results: The investigation on sickle cell anaemia women allowed to establish the relations between cardiac exergetic yield (η_{ex}) and differential pressure (P_D) called **KUNYIMA Relations** from the name of Dr. KUNYIMA BADIBANGA Anaclet, the designer of this research project. The sickle cell population under medical treatment exhibited in general very weak cardiac yield. Details in this paper show the linear dependence of cardiac yield on differential pressure as well for healthy persons as for sickle cell persons evidencing this ancient hypothesis according which the healthy person cardiac yield in the healthy environment remains constant (because P_D is constant). The difference between the healthy persons and sick persons resides in the slopes of straight lines.

Conclusion: So all biological system which is not in transient state works at constant cardiac yield. Also **KUNYIMA Equation** and **KUNYIMA Formula** have been successfully verified. An outstanding fact should be branded on memory: differential enthalpy is the total enthalpy accompanying the blood in its motion. With this paper the content of **Physical Cardiochemistry** as a research field is forthcoming and becomes a burning desire.

Keywords: Kunyima Equation; Kunyima Formula; Kunyima Chart; Volumic density of differential enthalpy; Exergetic cardiac yield; Physical Cardiochemistry.

ABBREVIATIONS

37 Systolic pressure (P_s); Diastolic pressure (P_d); Volumic density of differential enthalpy
 38 (ΔH_{DV}); Variation of the total differential enthalpy (ΔH_D) ; Volumic power or volumic
 39 density of power (P_V); Kunyima constants (k_K, Z_K); Technical volumic work power received
 40 by the system ($\dot{E}_V^+$); Cardiac exergetic yield (η_{ex}); Volumic exergetic loss in power or
 41 volumic density of exergetic loss in power ($\dot{L}_V$); Massic entropy variation (Δs); KUNYIMA
 42 Unit (Ky $\longrightarrow$ pl. Kys); Watt Keith Flack (W_{KF}).

43 1. INTRODUCTION

44 The sickle cell anaemia is a genetics sickness, autosomal, recessive, secondary to a punctual
 45 mutation at sixth codon level of β globine gene with substitution of glutamic acid by valine
 46 [1]. The prevalence of S hemoglobin is relatively high, reaching 40 % of central Africa
 47 population [2].

48 The morbidity is linked to acute and chronic complications and to their psychosocial and
 49 economics impact. The mortality is relatively high, specially for the children having less than
 50 five years old [3]. In Democratic Republic of Congo the prevalence of hemoglobin S is from
 51 28% to 45% [2].

52 Socially, the patients are confronted to the problems of their socioprofessional insertion
 53 (marriage, job) and from time to time to the relations impairment of couple. However despite
 54 the amplitude of the problem there is no health program to eradicate this husb [4].

55 **KUNYIMA Equation**, **KUNYIMA Formula** and **KUNYIMA Relations** have been
 56 successfully performed on sickle cell women under medical treatment in order to realize how
 57 their hearts are acting [5,6,7]. The difference in the slopes of straight lines have been
 58 observed. Volumic density of differential enthalpy, volumic density of work power, volumic
 59 density of cardiac power and exergetic cardiac power have been defined and dialed.

60 Theoretical survey

61 When a thermal well is at T_i temperature (blood for example at 37,4°C) higher than T_a
 62 temperature of an available thermal well (atmospheric air for example at 25°C), it becomes
 63 established natural transfers of heat between the two media. The quantity of released heat by
 64 such a source at T_i temperature can be the contribution of **exergy** (convertible part in
 65 mechanical work or part utilizable) and **anergy** (no convertible part in mechanical work or no
 66 useful part) [8,9,10].

$$67 \quad Q = Q_p + Q_a \quad (1)$$

68 On the other side it is known the human body is an open thermodynamics system exchanging
 69 heat and matter with outside and given the biological systems are essentially isothermics, one
 70 part of the heat (Q_p) from the exergonics biochemical reactions is used under coupling form
 71 to make possible the realization of vital processes such as muscular contractions, endergonics
 72 reactions, nerve conduction and active transfers. Another part of this heat (Q_a) is poured in

73 atmosphere. This no useful part (Q_a), compared to the atmosphere size, has no value and
 74 when it is received by the system (blood) it is gratis. So it can be neglected compared to Q_p
 75 and to atmospheric air content. The useful part Q_p measured at atmospheric pressure is
 76 identical to ΔH_D (differential enthalpy depending on differential pressure P_D) or ΔH_{cz} (total
 77 enthalpy containing ΔH , kinetic energy variation and potential energy variation). Indeed,
 78 according to the mechanical equation of thermodynamics first law for the open system
 79 containing a tensile fluid (capable to store the energy under pressure form) the following
 80 relation can be written [11,12,13],

$$81 \quad \Delta H_D = \Delta H_{cz} = - \int_{P_{in}}^{P_{out}} V dp = W_i + W_f + \Delta E_C + \Delta E_p \quad (2)$$

82 where W_i is the internal work of engine crossed by a fluid, P_{in} is the inlet pressure of the
 83 fluid and P_{out} its outlet pressure W_f is the internal dissipation, that means friction forces
 84 work or viscosity forces work (outside and inside forces) transformed in thermal energy by
 85 the internal dissipation phenomena. This work (W_f) is measured at atmospheric pressure and
 86 can be called ΔH .

87 So it can be written

$$88 \quad \Delta H_D = \Delta H_{cz} = - \int_{P_{in}}^{P_{out}} V dp = W_i + \Delta H + \Delta E_C + \Delta E_p \quad (3)$$

89 Applied to the fluid permanent flow in the fixed channel as in the case of blood in
 90 **KUNYIMA Chart** (schematic representation of heart in plane), Made in LACOPA/UNIKIN,
 91 DRC [13],

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93

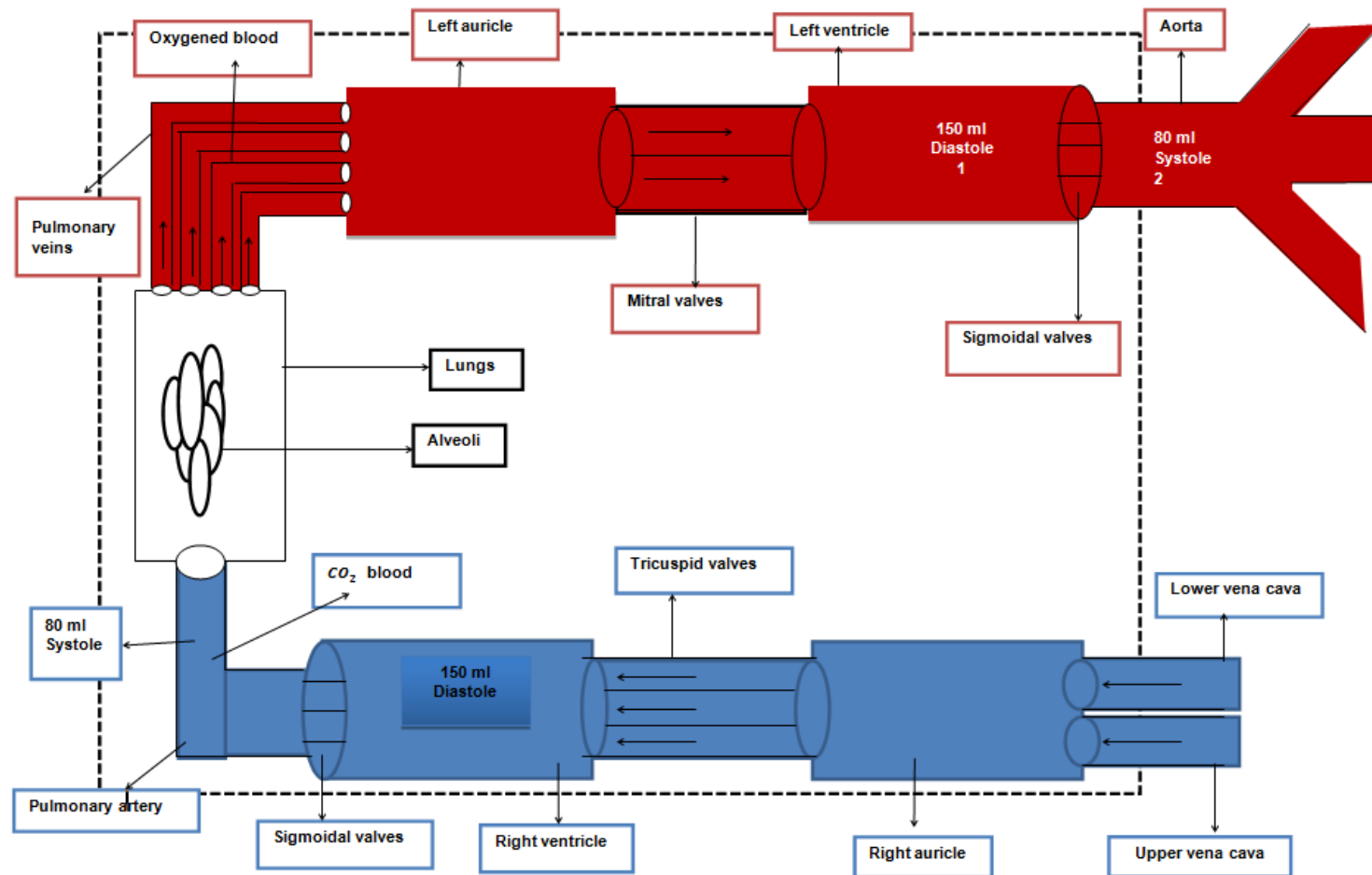


Fig. 1. KUNYIMA Chart (Schematic representation of the cardiac systems in a plane). Made in LACOPA/UNIKIN, DRC.

97 W_i is zero and the above mentioned equation becomes

$$98 \quad \Delta H_D = \Delta H_{cz} = - \int_{P_{in}}^{P_{out}} V dp = \Delta H + \Delta E_C + \Delta E_p \quad (4)$$

99 The minus sign conventionally means the system receives here the energy. Note that in the
100 case of the blood in KUNYIMA Chart however it has been adopted the contrary sign; the
101 inlet pressure is the systolic pressure (P_s) and the outlet pressure is the diastolic pressure (P_d).

$$102 \quad \Delta H_D = \Delta H_{cz} = - \int_{P_s}^{P_d} V dp = \Delta H + \Delta E_C + \Delta E_p$$

$$103 \quad \Delta H_D = \Delta H_{cz} = \Delta H + \frac{\Delta MC^2}{2} + \Delta MgZ = - \int_{P_s}^{P_d} V dp \quad (5)$$

104 Under massic form and if V (volume) is constant ($\rho = \frac{M}{V}$)

$$105 \quad \Delta h_D = \Delta h_{cz} = \Delta h + \frac{\Delta C^2}{2} + g\Delta Z = - \frac{V}{M} \int_{P_s}^{P_d} dp$$

$$106 \quad \Delta h_D = \Delta h_{cz} = \Delta h + \frac{\Delta C^2}{2} + g\Delta Z = - \frac{1}{\rho} (P_d - P_s) \quad (6)$$

107 It is clearly aimed here to demonstrate that the differential enthalpy is the total enthalpy
108 accompanying the fluid in its motion, fluid expelled under differential pressure. The problem
109 of sign (positive or negative) is merely conventional. Previously it has been demonstrated that
110 Δh_{cz} is relative to both stationary and motion states of fluid [13]. The theory it is speaking
111 about here is called exergetic theory combining the thermodynamics first and second laws. It
112 allows to define for any thermodynamics system (open or closed) the exergetic yield
113 expressing then its perfection degree or its thermodynamics quality. In this optics, it has been
114 demonstrated in the previous work [9,13] when a system of internal energy U_{cz} , under the
115 atmospheric influence (P_a, T_a), is the seat of work transfers, heat transfers and mass
116 transfers, the energetics balance in power is given by the following relation

$$117 \quad \frac{dU_{cz}}{dt} = \sum_k [\dot{E}_k^+] + \sum [\dot{Q}_i^+] + \sum [h_{czj} \dot{M}_j^+] \quad (7)$$

118 where

$$119 \quad U_{cz} = \text{the total internal energy} = U + \frac{MC^2}{2} + MgZ$$

120 $\dot{E}_k^+$ = global technical work power received by the system through the machine k

121 $\dot{Q}_i^+$ = heat power received by the system from the source at T_i temperature

122 $\dot{M}_j^+$ = mass debit of the fluid j received by the system

123 h_{czj} = massic total enthalpy of the fluid j

When the volume V of such a system increases of dV (volume of the fluid) a work power $P_a \frac{dV}{dt}$ is given by the system to the atmosphere. This power is not interesting for the researchers. What is interesting is the effective work power provided by the system:

$$\sum_k [\dot{E}_{ek}^-] = \sum_k [\dot{E}_k^-] - P_a \frac{dV}{dt} \quad (8)$$

The above mentioned equation can be written

$$\sum_k [\dot{E}_k^+] = \sum_k [\dot{E}_{ek}^+] - P_a \frac{dV}{dt} \quad (9)$$

The elimination of $[\dot{E}_k^+]$ between (7) and (9) gives the following energetic balance

$$\sum_k [\dot{E}_{ek}^+] + \sum_i [\dot{Q}_i^+] + \sum_j [h_{czj} \dot{M}_j^+] - \frac{d(U_{cz} + P_a V)}{dt} = 0 \quad (10)$$

where

$$U_{ecz} = U_{CZ} + P_a V \quad (11)$$

$$\text{So } \sum_k [\dot{E}_{ek}^+] + \sum_i [\dot{Q}_i^+] + \sum_j [h_{czj} \dot{M}_j^+] - \frac{dU_{ecz}}{dt} = 0 \quad (12)$$

and

$$\dot{W}_e^+ = \sum_j [h_{czj} \dot{M}_j^+] - \frac{dU_{ecz}}{dt} = \text{effective transformation power} \quad (13)$$

When the presence of a net n is signalized, net n defined as part of the system having contiguous spaces, susceptible to contain or to be crossed by fluids, it should be remembered this definition imply that two different nets are separated by a surface situated at the limit or inside solid wall. Those partition walls can be mobiles and conductors and so it can be observed through them only work transfers and heat transfers, not mass transfers [9,10]. It is consequently possible to define the effective transformation power received at each net level and the equation (12) can be written

$$\sum_k [\dot{E}_{ek}^+] + \sum_i [\dot{Q}_i^+] + \sum_n [\dot{W}_{en}^+] = 0 \quad (14)$$

where

$\dot{W}_{en}^+$ = effective transformation power received by the system at the level of the net n

$[\dot{Q}_i^+]$ of the equation (14) can be itemized as follow

$$\sum_k [\dot{E}_{ek}^+] + \sum_i [\int \delta \dot{Q}_i^+] + \dot{Q}_a^+ + \sum_n [\dot{W}_{en}^+] = 0 \quad (15)$$

where

150 $\dot{Q}_a^+$ = heat power received from atmosphere at T_a temperature

151 On the other side the second law of thermodynamics can be written

$$152 \quad \frac{dS}{dt} = \sum \left[\int \frac{\delta \dot{Q}_i^+}{T_i} \right] + \sum_j [s_j \dot{M}_j^+] + \frac{\delta \mathcal{S}^i}{dt} \quad (16)$$

153 where

154 s = entropy of the system

155 s_j = massic entropy of the fluid j

156 s_i = entropy due to the internal irreversibles operations

$$157 \quad \left(\frac{\delta s_i}{dt} \geq 0 \right)$$

158 Given the extensive property of entropy the sums can be made on the nets n and

$$159 \quad \frac{dS}{dt} \text{ can be replaced by } \sum_n \left[\frac{dS}{dt} \right]_n \quad (17)$$

$$160 \quad \sum_j [s_j \dot{M}_j^+] \text{ can be substituted by } \sum_n \left(\sum_j [s_j \dot{M}_j^+] \right)_n \quad (18)$$

$$161 \quad \sum_i \left[\int \frac{\delta \dot{Q}_i^+}{T_i} \right] \text{ can be detailed as } \sum_i \left[\int \frac{\delta \dot{Q}_i^+}{T_i} \right] + \frac{\dot{Q}_a^+}{T_a} \quad (19)$$

162 (17), (18) and (19) in (16) give rise to the following equation

$$163 \quad \sum_i \left[\int \frac{\delta \dot{Q}_i^+}{T_i} \right] + \frac{\dot{Q}_a^+}{T_a} + \sum_n \left(\sum_j [s_j \dot{M}_j^+] - \frac{dS}{dt} \right)_n + \frac{\delta \mathcal{S}^i}{dt} = 0 \quad (20)$$

164 Or

$$165 \quad \sum_i \left[\int \frac{T_a}{T_i} \delta \dot{Q}_i^+ \right] + \dot{Q}_a^+ + \sum_n \left(\sum_j [T_a s_j \dot{M}_j^+] - \frac{d(T_a S)}{dt} \right)_n + T_a \frac{\delta \mathcal{S}^i}{dt} = 0 \quad (21)$$

166

167 When the heat power $\dot{Q}_a^+$ between the equation (15) and (21) is eliminated, the following
168 equation is obtained

$$169 \quad \sum_k [\dot{E}_{ek}^+] + \sum_i \left[\int \left(1 - \frac{T_a}{T_i} \right) \delta \dot{Q}_i^+ \right] + \sum_n \left(\sum_j [(h_{eczj} - T_a s_j) \dot{M}_j^+] - \frac{d(U_{ecz} - T_a S)}{dt} \right)_n - T_a \frac{\delta \mathcal{S}^i}{dt} = 0 \quad (22)$$

170 Where it can be seen clearly new parameters:

$$\left\{ \begin{aligned} J_{cz} &= U_{ecz} - T_a S = U_{cz} + P_a V - T_a S = \text{total coenergy} \\ j_{cz} &= u_{ecz} - T_a s = u_{cz} + P_a v - T_a s = \text{massic coenergy} \end{aligned} \right\} \quad (23)$$

$$\left\{ \begin{aligned} K_{cz} &= H_{cz} - T_a S = \text{total coenthalpy} \\ k_{cz} &= h_{cz} - T_a s = \text{massic coenthalpy} \end{aligned} \right\} \quad (24)$$

$$\theta = \left(1 - \frac{T_a}{T_i}\right) = \text{Carnot factor} \quad (25)$$

$$\left\{ \begin{aligned} E_e^+ &= E^+ + P_a \Delta V = \text{effective work energy received by the system} \\ \dot{E}_e^+ &= \dot{E}^+ + P_a \frac{dV}{dt} = \text{effective work power received by the system} \end{aligned} \right\} \quad (26)$$

$$\left\{ \begin{aligned} E_Q^+ &= \int \theta \delta Q^+ = \text{heat cwork received by the system} \\ \dot{E}_Q^+ &= \int \theta \delta \dot{Q}^+ = \text{heat copower received by the system} \end{aligned} \right\} \quad (27)$$

$$\left\{ \begin{aligned} E_w^+ &= \sum_k [k_{czj} dM_j^+ - \Delta J_{cz}] = \text{transformation cwork received by the system} \\ \dot{E}_w^+ &= \sum [k_{czj} \dot{M}_j^+] - \frac{dJ_{cz}}{dt} = \text{transformation copower received by the system} \end{aligned} \right\} \quad (28)$$

$$\left\{ \begin{aligned} L &= T_a S_l \geq 0 = \text{exergitic loss in enegy} \\ \dot{L} &= T_a \frac{\delta S_l}{dt} \geq 0 = \text{exergitic loss in power} \end{aligned} \right\} \quad (29)$$

and the equation of exergetic balance in power becomes :

$$\sum_k [\dot{E}_{ek}^+] + \sum_i [\dot{E}_{qi}^+] + \sum_n [\dot{E}_{wn}^+] = \dot{L} \geq 0 \quad (30)$$

where

$\dot{E}_{ek}^+$ = effective work power received by the system

$\dot{E}_{qi}^+$ = heat copower received by the system at T_i temperature

$\dot{E}_{wn}^+$ = transformation copower received by the system through the flow net

When a system receives the energy, after the loss inside, the rest of energy can be given (continuing the transformation of the system). Hence the equation (30) is generally written

$$\sum_k [\dot{E}_{ek}^+] + \sum_i [\dot{E}_{qi}^+] + \sum_n [\dot{E}_{wn}^+] - \dot{L} = \sum_k [\dot{E}_{ek}^-] + \sum_i [\dot{E}_{qi}^-] + \sum_n [\dot{E}_{wn}^-] \quad (31)$$

So the exergetic yield is defined

$$\eta_{ex} = \frac{\sum_k [\dot{E}_{ek}^-] + \sum_i [\dot{E}_{qi}^-] + \sum_n [\dot{E}_{wn}^-]}{\sum_k [\dot{E}_{ek}^+] + \sum_i [\dot{E}_{qi}^+] + \sum_n [\dot{E}_{wn}^+]} = 1 - \frac{\dot{L}}{\sum_k [\dot{E}_{ek}^+] + \sum_i [\dot{E}_{qi}^+] + \sum_n [\dot{E}_{wn}^+]} \quad (32)$$

2. MATERIALS AND METHODS

a) Materials

Sphygmomanometer (Manual, type aneroid 767 Tycos mural de Welch Allyn) has been used [7,14,15]. The sickle cell anaemia persons were the target population. The experiments have been performed in Centre of Mixte Medicine and SS anaemia in Kinshasa called Centre MABANGA. The calculation have been done individually on the sample of 82 females whose the age varies between 13-57 years. The figures have been plotted by means of Origin 8 program. The Visio 2010 software was used for equations.

b) Methods

Prior to this paper [13], the bases of our thermodynamics system choice have been already thrown [5] and it will be cumbersome to repeat them here. Anyway it should be briefly recalled that the blood circulates in fixed channel considered as adiabatic (even though the probability of head transfer exists but negligible) with a mass debit $\dot{M}$ after having received $\dot{E}^+$ from Keith Flack influx supposed integrally transmitted (see time scale), through Aschoff Tawara node and His bundle, to ventricles in order to entail their contractions [5,7,16]. The differential enthalpy of the blood has been calculated according the relation

$\int dH = \int c_p dT + \int [V - T \left(\frac{\partial V}{\partial T} \right)_p] dp$. So the studied thermodynamics system is below represented

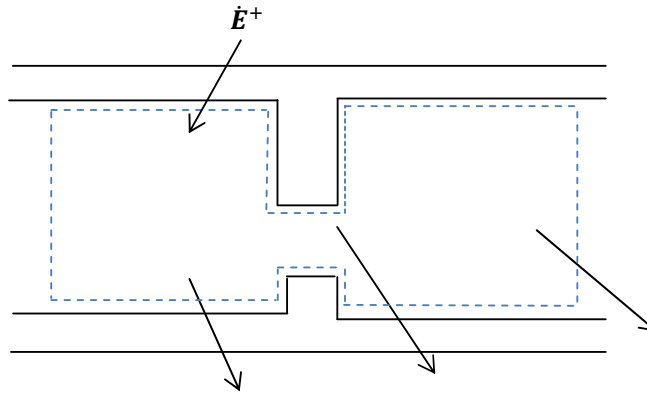


Fig.2. Studied thermodynamics system

This system is working in permanent regime, consequently

$$\frac{dU_{ecz}}{dt} = 0 \text{ and } \frac{dJ_{cz}}{dt} = 0 \text{ have been used.}$$

Indeed these formula containing the time dependent state variables are useful for a stationary system (permanent system) because then (at that time) their variations as a function of time are zero. How old a human organism representing an open system can be considered as being in stationary system to make possible the application of these equations because indeed it is known these state functions change with daily rhythm of life, with alimentary cycles and so

forth. It has been demonstrated that the human being is growing until 25years old and at this age he can be considered as an adult (a full-grown) and consequently the state functions fluctuations with time are zero. Such an organism can be described by the time independent state variables and it is not in equilibrium, but in stationary state out of the equilibrium. Hence its internal energy is time independent. But because it is spending the energy under heat and mechanical work form, the thermodynamics first law demands to profit the outside contribution in energy under a fit form. For an alive organism, this contribution is under chemical energy contained in consumed foods in order to maintain the stationary state out of the equilibrium. Also the organism must, to compensate the entropy production in it, dissipate the entropy through the exchange of heat and matter with its environment according to the thermodynamics second law $dS = 0$ ($d_i S = -d_o S$). The entropy production $d_i S > 0$ is coming from chemical reactions in the organism and the entropy dissipation $d_o S < 0$ originates, beyond the heat dissipation, from the clear exportation of entropy by means of the exchange of matter with the environment. Indeed the alive organisms consume the highest structural organization substances (weak entropy) decomposed by the biochemical reactions in great entropy products poured afterwards in environment (in outside milieu). For the alive organism under 25years, the variations of state functions with time are negligible in front of the first term of the definition [9,10]. The heart is of course concerned. According to the explanation in theory, the exergetic balance of the studied system is

$$\dot{E}_e^+ - \dot{L} = \dot{E}_w^- \quad (33)$$

And the energetic balance becomes evident

$$\dot{E}_e^+ = \dot{W}^- \quad (34)$$

According to the equation (13)

$$\dot{W}_e^+ = \dot{W}^+ = \sum [h_{czb} \dot{M}_b^+] = \dot{M}_b^+ [h_{cz(1)} - h_{cz(2)}]$$

(with index b = blood)

$$\begin{aligned} \dot{W}_e^+ = \dot{W}^+ &= -\dot{M}_b^+ [h_{cz(2)} - h_{cz(1)}] \\ \dot{W}_e^+ = \dot{W}^+ &= -\dot{M}_b^+ \Delta h_{cz} = -\dot{M}_b^+ \frac{1}{\rho} (P_d - P_s) \end{aligned} \quad [5]$$

$$\begin{aligned} \dot{E}_e^+ = \dot{W}^- &= -\dot{M}_b^+ \frac{1}{\rho} (P_d - P_s) \text{ with } \dot{M}_b^+ = \rho \dot{V} \\ \dot{E}_e^+ = \dot{V} (P_d - P_s) &= -V f_c (P_s - P_d) = -V k_k (P_s - P_d) \end{aligned} \quad (35)$$

with $f_c = k_k$ [6,7]

where $V = 80\text{mL}$, the ejected volume of blood [17] and f_c is the cardiac frequency.

According to the equation (26) the equation (35) becomes

$$\dot{E}^+ + P_a (\dot{V}_2 - \dot{V}_1) = -\dot{V} f_c (P_s - P_d)$$

$$\dot{E}^+ + P_a f_c (V_2 - V_1) = -V f_c (P_s - P_d)$$

$$\dot{E}^+ = -V f_C (P_s - P_d) - P_a f_C (V_2 - V_1)$$

$$\dot{E}^+ = -V f_C (P_s - P_d) + P_a f_C (V_1 - V_2) \quad (36)$$

$V_1 = 150\text{mL}$ of blood, $V_2 = V = 80\text{mL}$ of blood ejected in aorta $V_1 - V_2 = 70\text{mL}$ of blood [17,18,19,20]. This last equation (36) has been called “**KUNYIMA Formula**”[5]. $\dot{E}^+$ has been expressed in Watt Keith Flack to indicate the origin of this power. It has been decided in laboratory, in order to honour the name of **Dr. KUNYIMA BADIBANGA Anaclet**, Ordinary Professor at University of Kinshasa who proposed this expression, to give to this calculated work power the **unit KUNYIMA (Ky $\longrightarrow$ pl. Kys)**

So $1\text{Ky} = 1 \text{ Watt Keith Flack } (W_{KF})$

$2\text{Kys} = 2 \text{ Watt Keith Flack } (W_{KF})$

$1\text{kW Keith Flack } (W_{KF}) = 1000 \text{ W Keith Flack } (W_{KF}) = 1000 \text{ Kys}$

Using the exergetic balance nice information can be obtained about exergetic loss, entropy, coenthalpy and exergetic yield. Indeed

$$\dot{E}_e^+ - \dot{L} = \dot{E}_W^-$$

Equation (28) gives

$$\dot{E}_W^+ = \sum [k_{czb} \dot{M}_b^+] - \frac{dJ_{cz}}{dt}$$

$$\frac{dJ_{cz}}{dt} = 0 \text{ (permanent regime)}$$

$$\dot{E}_W^+ = \dot{M}_b^+ [k_{cz1} - k_{cz2}] ; \text{ with } k = h - T_a s$$

$$\dot{E}_W^+ = \dot{M}_b^+ [(h_{cz1} - T_a s_1) - (h_{cz2} - T_a s_2)]$$

$$\dot{E}_W^+ = \dot{M}_b^+ (h_{cz1} - h_{cz2}) - \dot{M}_b^+ T_a (s_1 - s_2)$$

$$\dot{E}_W^- = \dot{M}_b^+ (h_{cz2} - h_{cz1}) - \dot{M}_b^+ T_a (s_2 - s_1) \quad (37)$$

$$\dot{L} = \dot{E}_e^+ - \dot{E}_W^-$$

$$\dot{L} = \dot{E}^+ + P_a (\dot{V}_2 - \dot{V}_1) - [\dot{M}_b^+ (h_{cz2} - h_{cz1}) - \dot{M}_b^+ T_a (s_2 - s_1)]$$

$$\dot{L} = \dot{E}^+ + P_a (\dot{V}_2 - \dot{V}_1) - \dot{M}_b^+ (h_{cz2} - h_{cz1}) + \dot{M}_b^+ T_a (s_2 - s_1) \quad (38)$$

$$\dot{L} = \dot{E}^+ + P_a f_C (V_2 - V_1) - \rho V f_C (h_{cz2} - h_{cz1}) + \rho V f_C T_a (s_2 - s_1) \quad (39)$$

where $h_{cz2} - h_{cz1} = \Delta h_D$ [13]

The exergetic yield or exergetic cardiac yield is

$$\eta_{ex} = \frac{\dot{E}_W}{\dot{E}_e^+} = 1 - \frac{\dot{L}}{\dot{E}_e^+} = \left| \frac{P_C}{\dot{E}_e^+} \right|$$

where P_C is the cardiac power given by the system; conventionally it is in our case negative.

$$\eta_{ex} = \frac{-V f_C P_D}{-V f_C P_D + P_a f_C (V_1 - V_2)} = \left| \frac{-V f_C P_D}{P_a f_C (V_1 - V_2) - V f_C P_D} \right|$$

$$\eta_{ex} = \frac{P_D}{\left(\frac{V_1 - V_2}{V}\right) P_a - P_D} = \frac{P_D}{0.875 P_a - P_D} = \frac{P_D}{0.875 \times 760 - P_D} = \frac{P_D}{665 - P_D} \times 100 \quad (40)$$

for the healthy persons where P_D is in mmHg

For the persons whose V and $(V_1 - V_2)$ are not known the procedure is the following

$$|P_C| = |V f_C P_D|$$

$$|P_V| = \left| \frac{P_C}{V} \right| = |f_C P_D|$$

$$\dot{E}_V^+ = \frac{\dot{E}^+}{V} = -f_C P_D + P_a f_C$$

$\dot{E}_V^+$ is the volumic density of work power

$$\eta_{ex} = \left| \frac{f_C P_D}{P_a f_C - f_C P_D} \right| = \frac{P_D}{P_a - P_D}$$

$$\eta_{ex} = \frac{P_D}{P_a - P_D} \times 100 = \frac{P_D}{760 - P_D} \times 100 \quad (41)$$

Given the atmospheric pressure is constant note that the exergetic cardiac power depend only on differential pressure. The relations (40) and (41) have been called “**KUNYIMA Relations**” to honour the designer of LACOPA, **Dr. KUNYIMA BADIBANGA Anaclet**, who proposed them for the **practicians**. Now $\dot{L}$ can be obtained from the following relation

$$\dot{L} = (1 - \eta_{ex}) \dot{E}_e^+ \text{ and so } (s_2 - s_1) \text{ can be calcaled from equation (39)}$$

$$(s_2 - s_1) = \frac{\dot{L} - \dot{E}^+ + P_a f_C (V_2 - V_1) + \rho V f_C (h_{cz2} - h_{cz1})}{\rho V f_C T_a}$$

$$\text{with } (h_{cz2} - h_{cz1}) = \frac{1}{\rho} (P_d - P_s) = -\frac{1}{\rho} (P_s - P_d) = \Delta h_D$$

$$(s_2 - s_1) = \frac{\dot{L} - \dot{E}^+ - P_a f_C (V_2 - V_1) - V f_C (P_s - P_d)}{\rho V f_C T_a}$$

$$(s_2 - s_1) = \frac{\dot{L} - \dot{E}^+ - P_a f_C (V_2 - V_1) - V f_C P_D}{\rho V f_C T_a} \quad (42)$$

Where $\rho = 1,06 \text{ g/ml}$ = mean density of blood [10] and $T_a = 27^\circ\text{C} = 300 \text{ K}$ (atmospheric temperature)

$$P_a = 760 \text{ mmHg (atmospheric pressure)}$$

314 Substituting the value of $\dot{E}^+$ in equation (42)

$$315 \quad \dot{E}^+ = -V f_c P_D + P_a f_c (V_1 - V_2)$$

316 The following expression is obtained

$$317 \quad (s_2 - s_1) = \Delta s = \frac{\dot{L} + V f_c P_D - P_a f_c (V_1 - V_2) - P_a f_c (V_2 - V_1) - V f_c P_D}{\rho V f_c T_a}$$

$$318 \quad (s_2 - s_1) = \Delta s = \frac{\dot{L}}{\rho V f_c T_a} = \frac{\dot{L}_V}{\rho f_c T_a} \quad (43)$$

319 The precisions of the results have been calculated using logarithmic method. The following
320 relations have been used to calculate them. Note that for P_D the implemental error has been
321 used.

$$322 \quad \ln \Delta H_{DV} = -\ln P_D; \Delta \Delta H_{DV} = \left| \frac{\Delta P_D}{P_D} \right| \left| \Delta H_{DV} \right| \quad (44)$$

$$323 \quad \ln P_V = \ln f_c + \ln P_D; \Delta P_V = \left| \frac{\Delta P_D}{P_D} \right| P_V \quad (45)$$

$$324 \quad \ln \dot{E}_V^+ = \ln f_c + \ln (P_a - P_D); \Delta \dot{E}_V^+ = \left| \frac{\Delta P_D}{P_a - P_D} \right| \dot{E}_V^+ \quad (46)$$

$$325 \quad \ln \eta_{ex} = \ln \frac{P_D}{P_a - P_D}; \Delta \eta_{ex} = \left\{ \left| \frac{\Delta P_D}{P_D} \right| + \left| \frac{\Delta P_D}{760 - P_D} \right| \right\} \eta_{ex} \quad (47)$$

$$326 \quad \ln \dot{L}_V = \ln (1 - \eta_{ex}) + \ln P_V; \left| \Delta \dot{L}_V \right| = \left\{ \left| \frac{\Delta \eta_{ex}}{1 - \eta_{ex}} \right| + \left| \frac{\Delta P_V}{P_V} \right| \right\} \dot{L}_V \quad (48)$$

$$327 \quad \ln \Delta s = \ln \dot{L}_V - \ln \rho - \ln f_c - \ln T_a; \Delta \Delta s = \left\{ \left| \frac{\Delta \dot{L}_V}{\dot{L}_V} \right| + \left| \frac{\Delta \rho}{\rho} \right| \right\} \Delta s \quad (49)$$

328 To recap for the practitioners, KUNYIMA Formula takes the following forms:

$$329 \quad 1) \quad \dot{E}^+ = (x P_a - y P_D) f_c = Z_K f_c = Z_K k_K \quad (50)$$

330 with

$$331 \quad Z_K = (x P_a - y P_D) = \text{KUNYIMA constant at a given differential pressure } (P_D)$$

332 x is the difference between the ejected fraction of blood in aorta (mL) and the blood in left
333 ventricle before ejection.

334 y is the left ventricle ejected fraction of blood in aorta (mL) after contraction.

$$335 \quad 2) \quad \dot{E}_V^+ = \frac{\dot{E}^+}{V} = Z_K f_c = (P_a - P_D) f_c = Z_K k_K \quad (51)$$

336 with

$$337 \quad Z_K = P_a - P_D; P_a = \text{atmospheric pressure} = 1 \text{ atm} = 760 \text{ mm Hg.}$$

338 Z_K is the KUNYIMA constant at a given differential pressure (P_D)

339 To find in KUNYIMA Units $\dot{E}^+$ or $\dot{E}_V^+$ (**Kys or Kys/dm³**) a fit conversion must be done
340 (litre. atmosphère = 100 Joules ; 1 Atmosphère = 760 mm Hg ; Watt = Joule/sec ; 1 litre = 1 dm³).

341

342 **3. RESULTS AND DISCUSSION**

343 The table I is relative to measured and calculated parameters for sickle cell women.

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352 Table I. Measured and calculated parameters for sickle cell women

Age (ans)	P_s (mmHg)	P_d (mmHg)	$P_D + \Delta P_D$ (mmHg)	f_c (bpm)	$\Delta H_{DV} \pm \Delta \Delta H_{DV}$ (J/dm ³)	$P_V \pm \Delta P_V$ (W/dm ³)	$\dot{E}_V^+ \pm \Delta \dot{E}_V^+$ (Kys/dm ³)	η_{ex} (%)	$\dot{I}_V \pm \Delta \dot{I}_V$ (w/dm ³)	$\Delta s \pm \Delta \Delta s$ (Jkg ⁻¹ K ⁻¹)
13	97	93	4±0.5	90	-0.526±0.066	0.789±0.099	149.20±0.09	0.53±0.07	-0.785±0.155	-0.00164±0.00033
	96	80	16±0.5	96	-2.105±0.066	3.368±0.105	156.63±0.11	2.15±0.07	-3.296±0.132	-0.00648±0.00029
	109	80	29±0.5	106	-3.816±0.066	6.742±0.116	169.93±0.12	3.97±0.07	-6.474±0.117	-0.01151±0.00026
	119	89	30±0.5	108	-3.947±0.066	7.105±0.118	172.89±0.12	4.11±0.07	-6.813±0.119	-0.11892±0.00026
14	90	70	20±0.5	70	-2.632±0.066	3.071±0.077	113.50±0.08	2.70±0.07	-2.988±0.077	-0.0080±0.0002
	90	80	10±0.5	80	-1.316±0.066	1.755±0.088	131.50±0.09	1.33±0.07	-1.732±0.012	-0.0041±0.0002
	90	70	20±0.5	80	-2.632±0.066	3.509±0.088	129.80±0.09	2.70±0.07	-3.414±0.088	-0.0080±0.0002
	93	73	20±0.5	88	-2.632±0.066	3.860±0.097	142.70±0.10	2.70±0.07	-3.756±0.096	-0.0080±0.0002
	120	78	42±0.5	104	-5.526±0.066	9.578±0.114	163.70±0.11	5.85±0.07	-9.018±0.109	-0.0163±0.0003
	105	80	25±0.5	120	-3.289±0.066	6.578±0.132	193.60±0.13	3.36±0.07	-6.357±0.129	-0.0091±0.0003
15	105	60	45±0.5	70	-5.921±0.066	6.908±0.077	112.05±0.08	6.29±0.07	-6.473±0.073	-0.017431±0.00028
	108	82	26±0.5	84	-3.421±0.066	4.790±0.092	135.24±0.09	3.54±0.07	-4.611±0.090	-0.010400±0.00024
	90	80	10±0.5	83	-1.316±0.066	1.820±0.091	136.50±0.09	1.33±0.07	-1.796±0.094	-0.004079±0.00023
	100	80	20±0.5	90	-2.631±0.066	3.947±0.099	146.10±0.10	2.70±0.07	-3.840±0.098	-0.008000±0.00023
16	100	90	10±0.5	80	-1.316±0.066	1.754±0.088	131.56±0.09	1.33±0.07	-1.731±0.090	-0.004079±0.00024
	110	89	21±0.5	94	-2.763±0.066	4.329±0.103	152.46±0.10	2.84±0.07	-4.206±0.102	-0.008434±0.00023
	90	80	10±0.5	100	-1.316±0.066	2.193±0.101	164.50±0.11	1.33±0.07	-2.164±0.113	-0.004179±0.00022
	100	90	10±0.5	100	-1.316±0.066	2.193±0.101	164.50±0.11	1.33±0.07	-2.164±0.113	-0.004179±0.00022

	108	83	25±0.5	100	-3.290±0.066	5.483±0.101	161.36±0.11	3.40±0.07	-5.296±0.108	-0.00998±0.00028
17	117	94	23±0.5	95	-3.026±0.066	4.792±0.104	153.55±0.10	3.12±0.07	-4.642±0.102	-0.00921±0.00020
	113	88	25±0.5	95	-3.290±0.066	5.208±0.104	153.23±0.10	3.40±0.07	-5.031±0.102	-0.00998±0.00023
	107	82	25±0.5	100	-3.290±0.066	5.483±0.101	161.36±0.11	3.40±0.07	-5.296±0.109	-0.00998±0.00029
18	108	70	38±0.5	83	-5.000±0.066	6.917±0.091	131.36±0.09	5.26±0.07	-6.553±0.087	-0.01488±0.00030
	109	85	24±0.5	90	-3.158±0.066	4.737±0.099	145.35±0.10	3.26±0.07	-4.582±0.0972	-0.00960±0.00029
	100	60	40±0.5	102	-5.263±0.066	8.947±0.112	161.16±0.11	5.56±0.07	-8.450±0.107	-0.001562±0.00020
	100	60	40±0.5	102	-5.263±0.066	8.947±0.112	161.16±0.11	5.56±0.07	-8.450±0.107	-0.01562±0.00020
	108	83	25±0.5	103	-3.290±0.066	5.647±0.113	166.20±0.11	3.40±0.07	-5.455±0.111	-0.00998±0.00050
19	134	82	52±0.5	64	-6.842±0.066	7.298±0.070	99.44±0.07	7.34±0.07	-6.762±0.066	-0.01992±0.00030
	116	64	52±0.5	88	-6.842±0.066	10.035±0.097	136.60±0.10	7.34±0.07	-9.298±0.090	-0.01992±0.00030
	119	74	45±0.5	108	-5.921±0.066	10.658±0.118	169.38±0.12	6.29±0.07	-9.987±0.112	-0.01743±0.00028
	120	74	46±0.5	120	-6.053±0.066	12.105±0.132	188.00±0.13	6.44±0.08	-11.325±0.125	-0.01780±0.00025
20	120	80	40±0.5	90	-5.263±0.066	7.895±0.099	142.20±0.10	5.56±0.07	-7.456±0.095	-0.01562±0.00027
	110	65	45±0.5	100	-5.921±0.066	9.869±0.101	156.80±0.11	6.29±0.07	-9.184±0.104	-0.01743±0.00029
	115	83	32±0.5	125	-4.211±0.066	8.772±0.137	199.55±0.14	4.40±0.07	-8.386±0.133	-0.01265±0.00030
	110	80	30±0.5	125	-3.947±0.066	8.224±0.137	200.17±0.14	4.11±0.07	-7.885±0.133	-0.01189±0.00027
21	93	65	28±0.5	94	-3.684±0.066	5.772±0.103	151.05±0.10	3.83±0.07	-5.551±0.100	-0.01113±0.00026
	125	75	50±0.5	95	-6.579±0.066	10.417±0.104	148.01±0.10	7.04±0.08	-9.683±0.098	-0.01921±0.00029

22	85	70	15±0.5	62	-1.974±0.066	2.039±0.068	102.68±0.07	0.66±0.07	-2.026±0.070	-0.00616±0.00021
	93	62	31±0.5	73	-4.079±0.066	4.963±0.080	116.83±0.08	4.25±0.07	-4.752±0.078	-0.01227±0.00031
	103	68	35±0.5	76	-4.605±0.066	5.833±0.083	120.87±0.08	4.83±0.07	-5.552±0.080	-0.01377±0.00030
	110	69	41±0.5	92	-5.395±0.066	8.272±0.101	145.17±0.10	5.70±0.07	-7.800±0.096	-0.01598±0.00032
	108	90	18±0.5	93	-2.368±0.066	3.671±0.102	151.43±0.10	2.423±0.07	-3.582±0.101	-0.00726±0.00024
	116	81	35±0.5	105	-4.605±0.066	8.059±0.115	166.95±0.12	4.828±0.07	-7.670±0.111	-0.01377±0.00028
23	110	80	30±0.5	100	-3.947±0.066	6.579±0.101	160.19±0.11	4.11±0.07	-6.309±0.108	-0.01189±0.00027
	95	70	25±0.5	115	-3.290±0.066	6.305±0.126	93.86±0.06	3.40±0.07	-6.090±0.126	-0.00998±0.00020
	109	93	16±0.5	124	-2.105±0.066	4.351±0.136	202.35±0.14	2.15±0.07	-4.257±0.136	-0.00863±0.00021
24	100	60	40±0.5	70	-5.263±0.066	6.140±0.077	110.53±0.08	5.56±0.07	-5.799±0.074	-0.01562±0.00028
	107	80	27±0.5	70	-3.553±0.066	4.145±0.077	112.51±0.08	3.68±0.07	-3.992±0.075	-0.01075±0.00030
	107	95	12±0.5	93	-1.579±0.066	2.447±0.102	152.67±0.10	1.60±0.07	-2.408±0.103	-0.00488±0.00021
	117	60	57±0.5	90	-7.500±0.066	11.250±0.099	138.75±0.10	8.11±0.07	-10.338±0.092	-0.02165±0.00014
	108	80	28±0.5	100	-3.684±0.066	6.140±0.111	160.69±0.11	3.83±0.07	-5.905±0.108	-0.01113±0.00028
	100	70	30±0.5	100	-3.947±0.066	6.579±0.111	160.19±0.11	4.10±0.07	-6.309±0.108	-0.01189±0.00030
25	109	63	46±0.5	75	-6.053±0.066	7.566±0.082	117.50±0.08	6.44±0.07	-7.079±0.082	-0.01779±0.00029
	111	73	38±0.5	76	-5.000±0.066	6.333±0.083	120.27±0.08	5.26±0.07	-5.999±0.083	-0.01488±0.00028
	90	73	17±0.5	76	-2.237±0.066	2.833±0.083	123.76±0.08	2.29±0.07	-2.769±0.083	-0.00687±0.00024
	90	69	21±0.5	83	-2.763±0.066	3.822±0.091	134.51±0.09	2.84±0.07	-3.758±0.095	-0.00843±0.00020
26	110	80	30±0.5	80	-3.947±0.057	4.563±0.075	128.04±0.09	4.11±0.07	-5.047±0.067	-0.01189±0.00021

	108	66	42±0.5	92	-5.526±0.066	8.474±0.101	144.83±0.10	5.85±0.07	-7.978±0.101	-0.01635±0.0028
27	115	90	25±0.5	70	-3.289±0.066	3.837±0.077	112.75±0.08	3.40±0.07	-3.707±0.077	-0.00998±0.00025
	109	88	21±0.5	94	-2.763±0.066	4.329±0.103	152.31±0.10	2.84±0.06	-4.206±0.103	-0.00843±0.00025
28	105	72	33±0.5	93	-4.3421±0.066	6.730±0.102	148.34±0.10	4.54±0.07	-6.425±0.102	-0.01302±0.00027
	120	100	20±0.5	98	-2.6326±0.066	4.299±0.107	159.05±0.11	2.70±0.07	-4.183±0.107	-0.00805±0.00024
29	119	94	25±0.5	90	-3.289±0.065	4.934±0.099	145.07±0.10	3.40±0.07	-4.766±0.012	-0.00998±0.00030
	96	66	30±0.5	96	-3.947±0.066	6.315±0.105	153.68±0.11	4.11±0.07	-6.055±0.105	-0.01189±0.00026
	90	70	20±0.5	98	-2.632±0.066	4.298±0.107	159.05±0.11	2.70±0.07	-4.182±0.108	-0.00804±0.00024
	111	94	17±0.5	99	-2.237±0.066	3.691±0.109	161.31±0.11	2.29±0.07	-3.607±0.108	-0.00687±0.00024

30	108	80	28±0.5	73	-3.684±0.066	4.482±0.080	117.18±0.08	3.82±0.07	-4.311±0.080	-0.00111±0.00107
	114	97	17±0.5	96	-2.237±0.066	3.579±0.105	156.42±0.11	2.29±0.07	-3.497±0.105	-0.00687±0.00024
31	108	93	15±0.5	94	-1.974±0.066	3.093±0.103	153.72±0.10	2.01±0.07	-3.029±0.103	-0.00608±0.00064
32	100	70	30±0.5	83	-3.947±0.066	5.461±0.0910	132.87±0.09	4.11±0.07	-5.236±0.091	-0.01189±0.00026
33	98	62	36±0.5	104	-4.747±0.066	8.211±0.114	165.12±0.11	4.97±0.07	-7.802±0.110	-0.01414±0.00027
34	115	95	20±0.5	80	-2.632±0.066	3.509±0.088	129.83±0.09	2.70±0.07	-3.414±0.087	-0.00804±0.00024
	114	80	34±0.5	85	-4.474±0.066	6.338±0.093	135.32±0.09	4.68±0.07	-6.041±0.090	-0.01340±0.00028
	108	65	43±0.5	93	-5.658±0.066	8.770±0.102	146.17±0.10	5.99±0.07	-8.244±0.097	-0.01671±0.00030
	103	80	23±0.5	98	-3.026±0.066	4.943±0.108	158.40±0.11	3.12±0.07	-4.789±0.105	-0.00921±0.00020
43	132	90	42±0.5	90	-5.526±0.066	8.290±0.099	141.75±0.10	5.85±0.07	-7.80±0.094	-0.01637±0.00030
47	123	76	47±0.5	87	-6.184±0.066	8.967±0.095	136.01±0.10	6.59±0.07	-8.376±0.090	-0.01815±0.00030
	123	76	47±0.5	87	-6.184±0.066	8.967±0.095	136.01±0.10	6.59±0.07	-8.376±0.090	-0.01815±0.00030
52	109	93	16±0.5	85	-2.105±0.066	2.983±0.093	138.72±0.09	2.15±0.07	-2.918±0.093	-0.00647±0.00023
	108	73	35±0.5	88	-4.605±0.066	6.754±0.097	139.86±0.10	4.83±0.07	-6.428±0.093	-0.01377±0.00029
57	109	83	26±0.5	106	-3.421±0.066	6.044±0.116	170.60±0.12	3.54±0.07	-5.830±0.114	-0.01037±0.00024

This table I has been, for good analysis, divided into table I.1 to table I.14 and the illustrative figures (corresponding figures) have been drawn.

Table I.1. Volumic density of cardiac power (P_V) as a function of differential pressure (P_D) at cardiac frequency of 70 bpm.

It is observed here that at a fixed cardiac frequency ($f_c = 70\text{bpm}$). P_V is a linear function of P_D (Fig.3).

f_c (bpm)	$P_D \pm \Delta P_D$ (mmHg)	$P_V \pm \Delta P_V$ (W/dm ³)
70	20 $\pm$ 0.5	3.071 $\pm$ 0.077
	25 $\pm$ 0.5	3.837 $\pm$ 0.077
	27 $\pm$ 0.5	4.145 $\pm$ 0.077
	40 $\pm$ 0.5	6.140 $\pm$ 0.077
	45 $\pm$ 0.5	6.908 $\pm$ 0.077

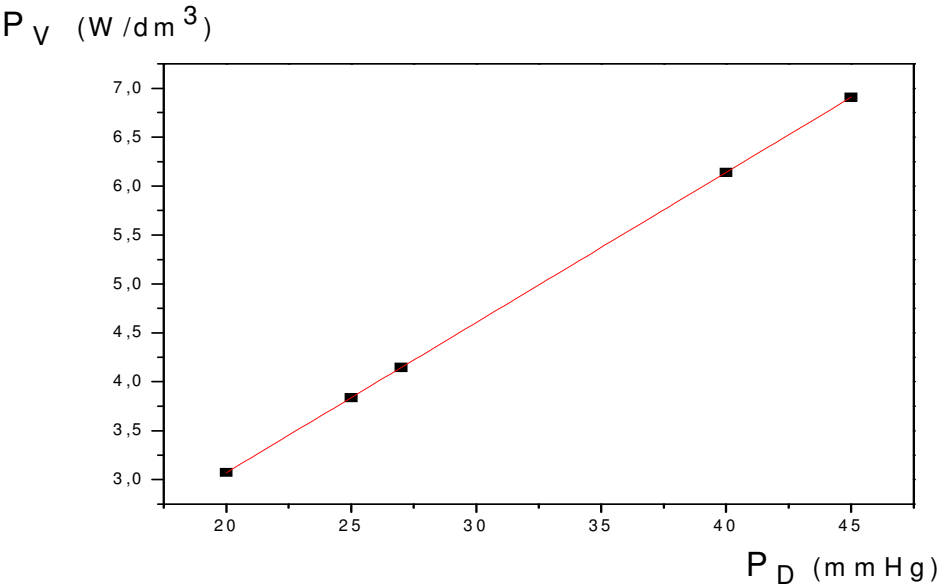


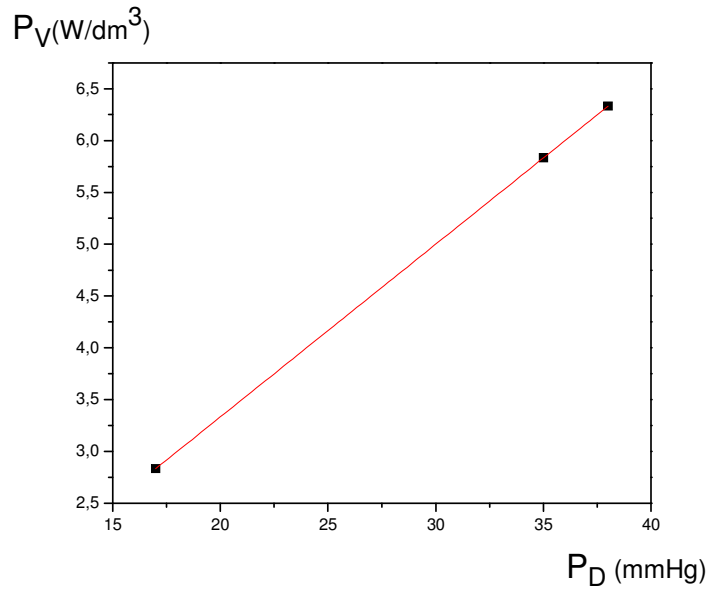
Fig. 3. P_V versus P_D at $f_c = 70$ bpm

Table I.2. Volumic density of cardiac power (P_V) as a function of differential pressure at $f_c = 76$ bpm.

Likewise P_V is linear function of P_D (Fig. 4).

f_c (bpm)	$P_D + \Delta P_D$ (mmHg)	$P_V \pm \Delta P_V$ (W/dm ³)
76	17±0.5	2.833±0.083
	35±0.5	5.833±0.083
	38±0.5	6.333±0.083

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369

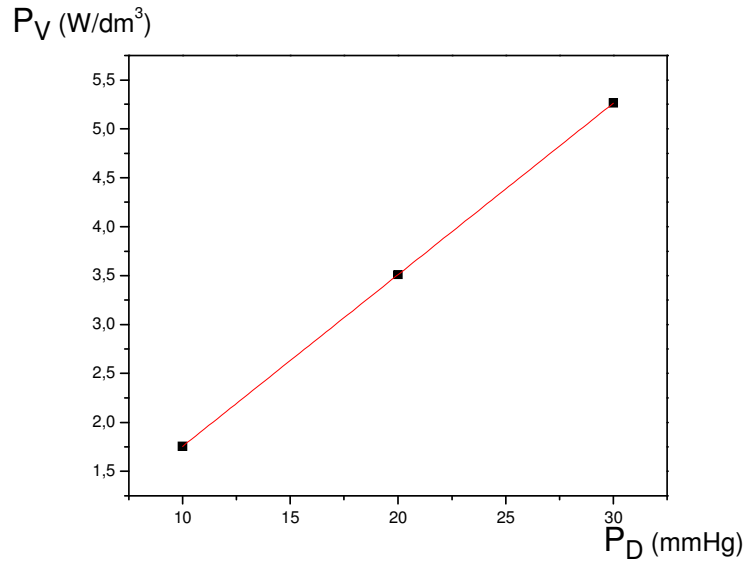
370 **Fig. 4. P_V versus P_D at $f_c = 76$ bpm**

371 **Table I.3. Volumic density of cardiac power (P_V) as a function of differential pressure at**
372 **$f_c = 80$ bpm.**

373 It can be seen also that KUNYIMA Equation is verified (Fig. 5).

f_c (bpm)	$P_D + \Delta P_D$ (mmHg)	$P_V \pm \Delta P_V$ (W/dm ³)
80	10±0.5	1.755±0.088
	20±0.5	3.509±0.088
	30±0.5	5.263±0.088

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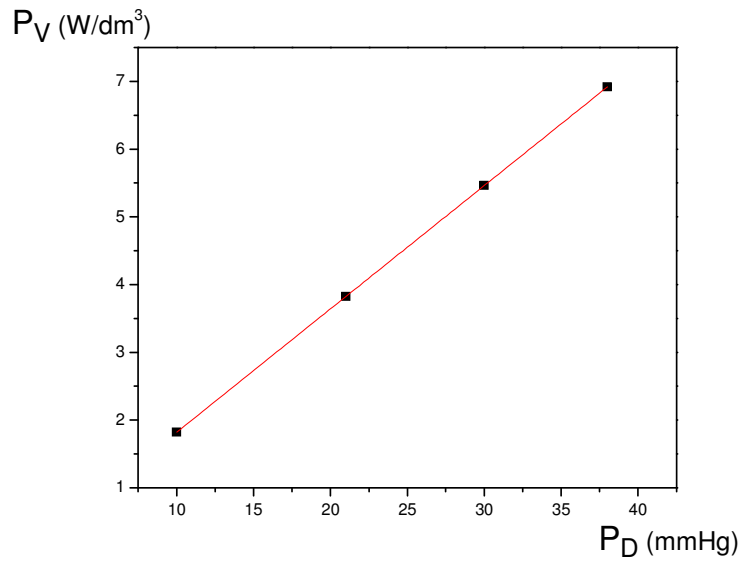
376 **Fig. 5. P_V versus P_D at $f_c = 80$ bpm**

377 **Table I.4. Volumic density of cardiac power (P_V) as a function of differential pressure at**
 378 **$f_c = 83$ bpm.**

379 The evolution P_V as a function of P_D is linear and KUNYIMA Equation is verified (Fig.6).

f_c (bpm)	$P_D + \Delta P_D$ (mmHg)	$P_V \pm \Delta P_V$ (W/dm ³)
83	10 $\pm$ 0.5	1.820 $\pm$ 0.091
	21 $\pm$ 0.5	3.822 $\pm$ 0.091
	30 $\pm$ 0.5	5.461 $\pm$ 0.091
	38 $\pm$ 0.5	6.917 $\pm$ 0.091

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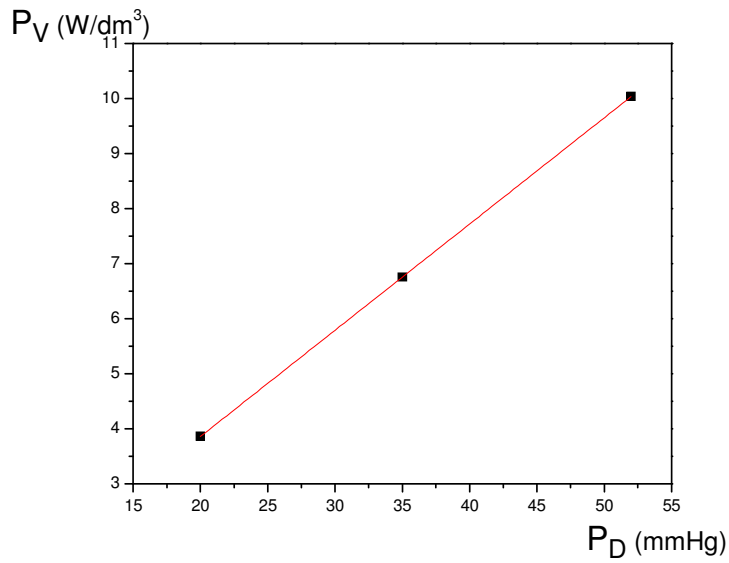
382 **Fig. 6. P_V versus P_D at $f_c = 83$ bpm**

383 **Table I.5. Volumic density of cardiac power (P_V) as a function of differential pressure at**
 384 **$f_c = 88$ bpm.**

385 **The verification of KUNYIMA Equation is without failure (Fig.7).**

f_c (bpm)	$P_D + \Delta P_D$ (mmHg)	$P_V \pm \Delta P_V$ (W/dm ³)
88	20±0.5	3.860±0.097
	35±0.5	6.754±0.097
	52±0.5	10.035±0.097

386



387

388 **Fig. 7. P_V versus P_D at $f_c = 88$ bpm**

389 **Table I.6. Volumic density of cardiac power (P_V) as a function of differential pressure at**
 390 **$f_c = 90$ bpm.**

391 P_V is linear function of P_D (KUNYIMA Equation is verified).

f_c (bpm)	$P_D \pm \Delta P_D$ (mmHg)	$P_V \pm \Delta P_V$ (W/dm³)
90	20±0.5	3.947±0.099
	24±0.5	4.737±0.099
	25±0.5	4.934±0.099
	40±0.5	7.895±0.099
	42±0.5	8.304±0.099
	57±0.5	11.250±0.099

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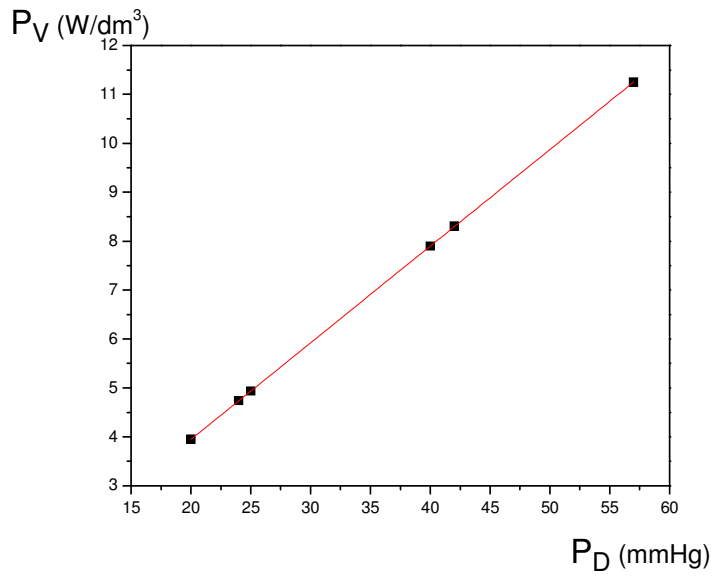
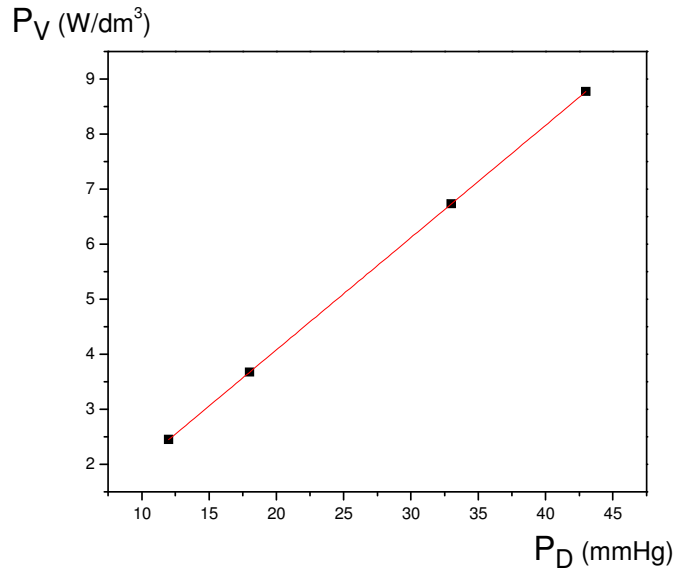


Fig. 8. P_V versus P_D at $f_c = 90$ bpm

Table I.7. Volumic density of cardiac power (P_V) as a function of differential pressure at $f_c = 93$ bpm.

KUNYIMA Equation is verified as it is shown in figure 9.

f_c (bpm)	$P_D + \Delta P_D$ (mmHg)	$P_V \pm \Delta P_V$ (W/dm ³)
93	12 $\pm$ 0.5	2.447 $\pm$ 0.102
	18 $\pm$ 0.5	3.671 $\pm$ 0.102
	33 $\pm$ 0.5	6.730 $\pm$ 0.102
	43 $\pm$ 0.5	8.770 $\pm$ 0.102



401

402 **Fig. 9. P_V versus P_D at $f_c = 93$ bpm**

403 **Table I.8. Volumic density of cardiac power (P_V) as a function of differential pressure at**
 404 **$f_c = 94$ bpm**

405 **No matter how many points we have, KUNYIMA Equation is successfully verified (Fig.10).**

f_c (bpm)	$P_D \pm \Delta P_D$ (mmHg)	$P_V \pm \Delta P_V$ (W/dm³)
94	15±0.5	3.092±0.103
	21±0.5	4.329±0.103
	28±0.5	5.772±0.103

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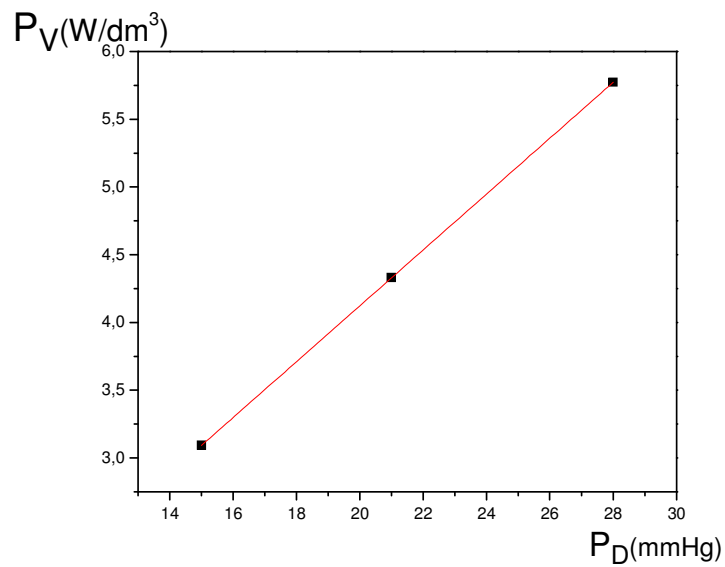
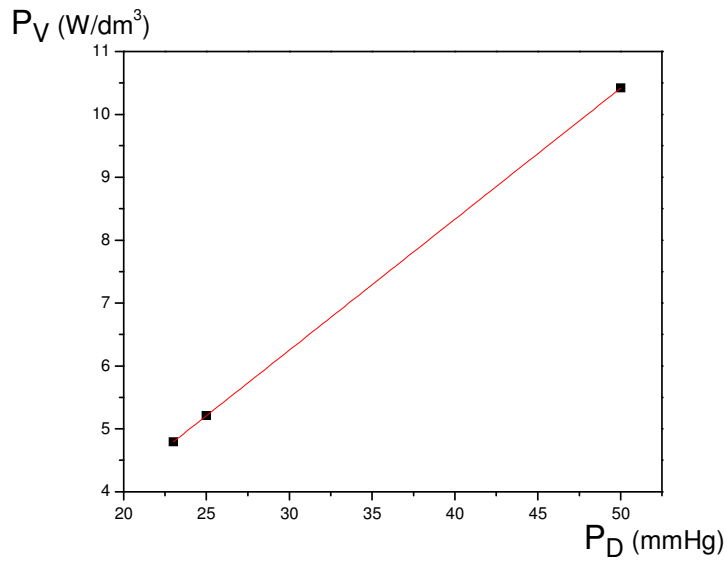


Fig. 10. P_V versus P_D at $f_c = 94$ bpm

Table I.9. Volumic density of cardiac power (P_V) as a function of differential pressure at $f_c = 95$ bpm.

KUNYIMA Equation is evidently verified (Fig.11).

f_c (bpm)	$P_D + \Delta P_D$ (mmHg)	$P_V \pm \Delta P_V$ (W/dm³)
95	23±0.5	4.792±0.104
	25±0.5	5.208±0.104
	50±0.5	10.417±0.104



415

416 **Fig. 11. P_V versus P_D at $f_c = 95$ bpm**

417 **Table I.10. Volumic density of cardiac power (P_V) as a function of differential pressure**
 418 **at $f_c = 100$ bpm.**

419 At any fixed cardiac frequency KUNYIMA Equation is always verified as it can be finally
 420 see in figure 12.

421

f_c (bpm)	$P_D \pm \Delta P_D$ (mmHg)	$P_V \pm \Delta P_V$ (W/dm³)
100	10 $\pm$ 0.5	2.193 $\pm$ 0.101
	25 $\pm$ 0.5	5.483 $\pm$ 0.101
	28 $\pm$ 0.5	6.140 $\pm$ 0.101
	30 $\pm$ 0.5	6.579 $\pm$ 0.101
	45 $\pm$ 0.5	9.869 $\pm$ 0.101

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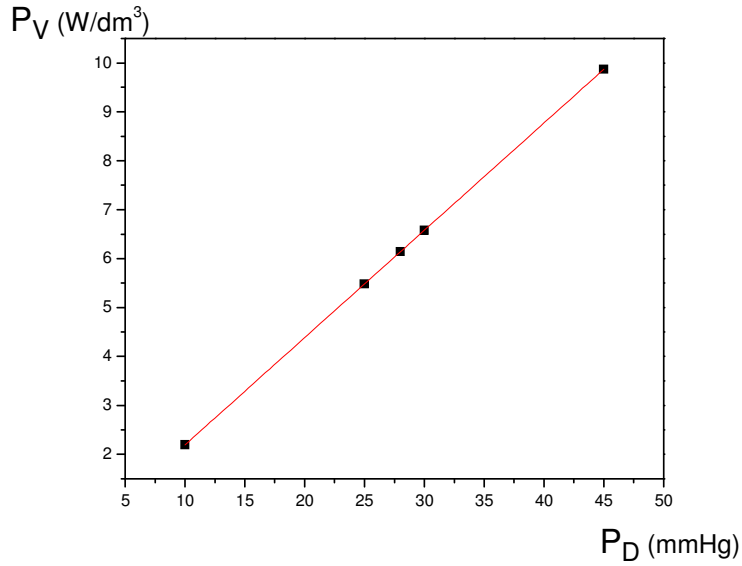
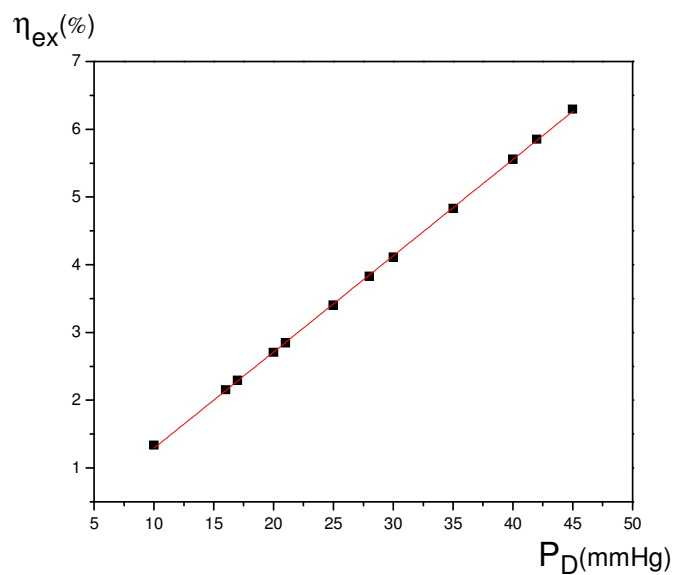


Fig. 12. P_V versus P_D at $f_c = 100$ bpm

Table I.11. Cardiac exergetic yield as a function of differential pressure.

This table shows the evolution of cardiac exergetic yield with the differential pressure where it can be seen in figure 13 the linear dependence. This result is very important because it should be noted that η_{ex} depend only on P_D and on this assertion it can be undertaken to focus a new model of sphygmomanometer with this further parameter (η_{ex}) easily calculated.

$\eta_{ex} \pm \Delta\eta_{ex}$ (%)	$P_D + \Delta P_D$ (mmHg)
1.333±0.0007	10±0.5
2.150±0.0007	16±0.5
2.288±0.0007	17±0.5
2.703±0.0007	20±0.5
2.842±0.0007	21±0.5
3.401±0.0007	25±0.5
3.825±0.0007	28±0.5
4.110±0.0007	30±0.5
4.828±0.0007	35±0.5
5.556±0.0007	40±0.5
5.850±0.0007	42±0.5
6.294±0.0007	45±0.5



431

432 **Fig. 13. η_{ex} versus P_D**

433 **Table I.12. Volumic density of differential enthalpy as a function of differential pressure**

434 It can be pointed out here that the absolute value of ΔH_{DV} is equal to P_D .

435

$\Delta H_{DV} \pm \Delta \Delta H_{DV}$ (J/dm ³)	$P_D \pm \Delta P_D$ (mmHg)
1.316±0.066	10±0.5
2.105±0.066	16±0.5
2.237±0.066	17±0.5
2.631±0.066	20±0.5
2.763±0.066	21±0.5
3.290±0.066	25±0.5
3.684±0.066	28±0.5
3.947±0.066	30±0.5
4.605±0.066	35±0.5
5.263±0.066	40±0.5
5.526±0.066	42±0.5
5.921±0.066	45±0.5

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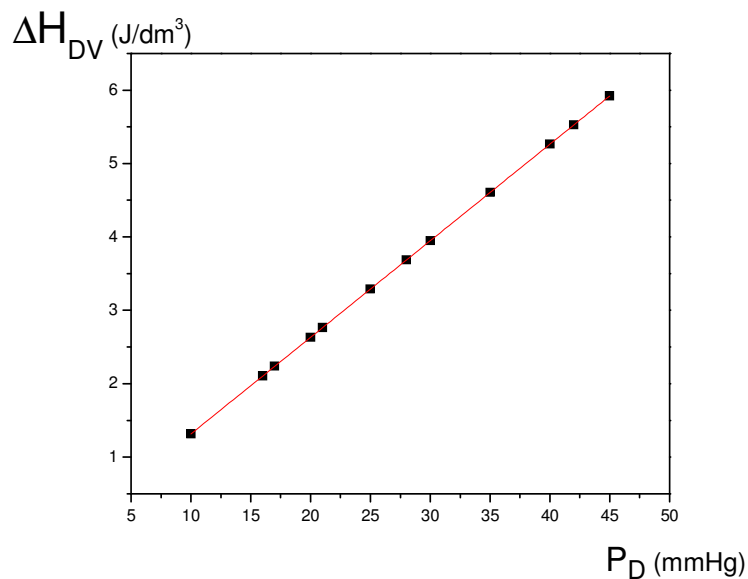


Fig. 14. ΔH_{DV} versus P_D

Table I.13. Volumic density of work power ($\dot{E}_V^+$) as a function of cardiac frequency at $P_D = 30$ mm Hg.

Also it can be seen that at any fixed P_D the linear variation of $\dot{E}_V^+$ versus f_c is observed (Fig.15).

$\dot{E}_V^+$ (Kys /dm ³)	f_c (bpm)
128.04±0.09	80
132.87±0.09	83
153.68±0.11	96
160.19±0.11	100
172.89±0.12	108
200.17±0.14	125

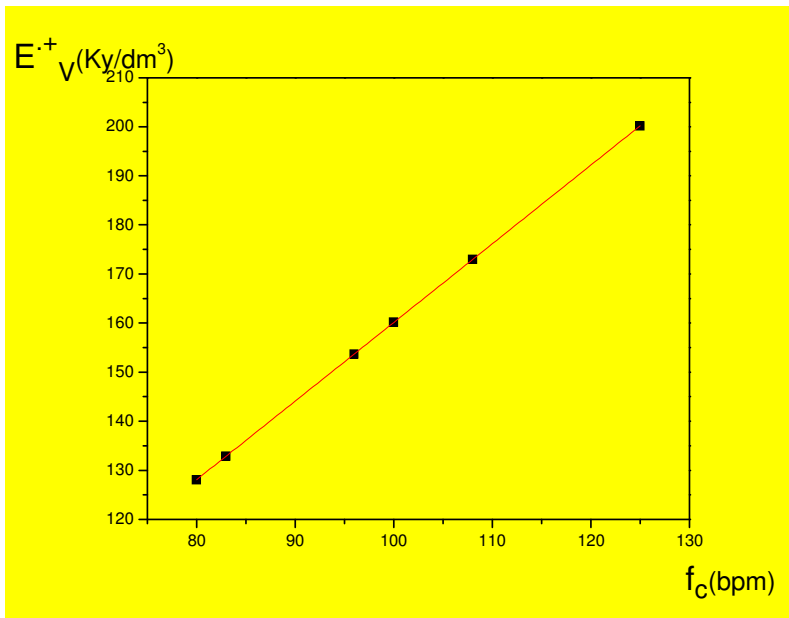


Fig. 15. E_v^+ versus f_c at $P_D = 30$ mm Hg

Table I.14. Volumic density of work power ($\dot{E}_v^+$) as a function of $(P_a - P_D)$ at $f_c = 70$ bpm for example.

The figure of this table I.14 has not been plotted but it can be observed that the change of $\dot{E}_v^+$ versus $(P_a - P_D)$ is small. The situation is the same at any fixed f_c (table I).

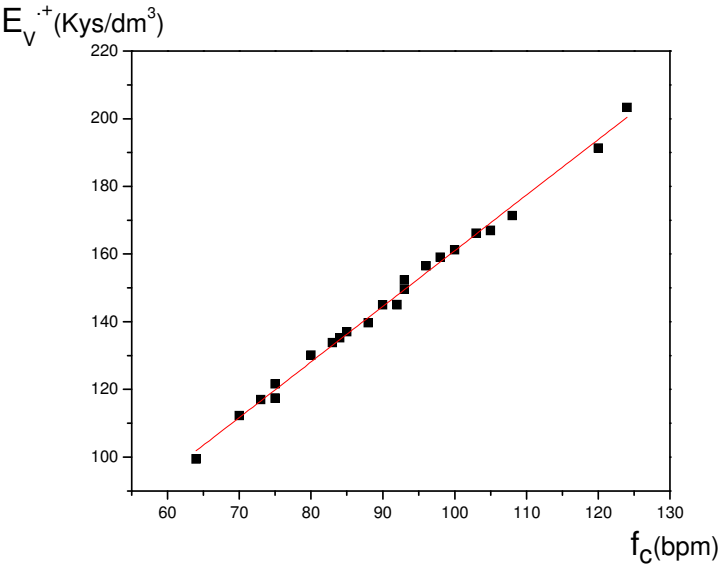
$\dot{E}_v^+$ (Kys /dm ³)	$(P_a - P_D)$ (mm Hg)
112.05±0.08	715
110.53±0.08	720
112.51±0.08	733
112.75±0.08	735
113.50±0.08	740

Table I.15. Volumic density of work power ($\dot{E}_v^+$) as a function of cardiac frequency (f_c)

$\dot{E}_v^+$ changes with both the cardiac frequency and the difference $(P_a - P_D)$. To realize the great influence of cardiac frequency on $\dot{E}_v^+$ it has been plotted the values of $\dot{E}_v^+$ versus f_c at different differential pressures. A straight line has been observed giving $(P_a - P_D)$ constant meaning that $\dot{E}_v^+$ depends more on f_c than on P_D as it can be seen in figure 16.

$\dot{E}_V^+$ (Kys /dm ³)	f_c (bpm)
99.44±0.07	64
112.29±0.08	70
117.01±0.08	73
117.43±0.08	75
121.63±0.08	76
130.15±0.09	80
133.81±0.09	83
135.24±0.09	84
137.02±0.09	85
139.72±0.09	88
144.95±0.10	90
145.00±0.10	92
149.65±0.10	93
152.35±0.10	94
156.53±0.11	96
159.05±0.11	98
161.18±0.11	100
166.20±0.11	103
166.95±0.11	105
169.38±0.11	108
191.00±0.12	120
203.35±0.14	124

461



462

463 **Fig. 16.** $\dot{E}_V^+$ versus f_c

464

465

466 **Table I.16.** Volumic density of exergetic loss in power ($\dot{L}_V$) as a function of cardiac
 467 frequency (f_c)

468 This table I.16 is brought out from table I at differential pressure (P_D)

$\dot{L}_V$ (W /dm ³) Average	f_c (bpm)
2.026	62
6.762	64
4.592	70
4.532	73
6.443	75
4.368	76
3.068	80
4.036	83
4.620	84
4.480	85
8.376	87
6.494	88
5.833	90
7.978	92
5.165	93
4.248	94
6.452	95
4.676	96
4.183	98
3.607	99
5.333	100
8.450	102
5.455	103
8.410	104
7.670	105
6.474	106
6.813	108
6.090	115
11.325	120
4.257	124
8.136	125

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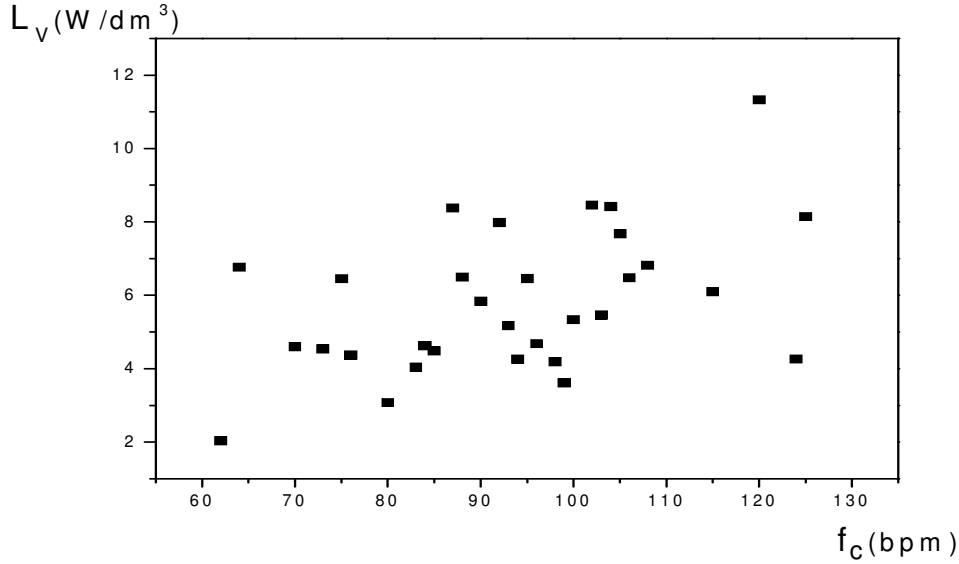


Fig. 17. $\dot{L}_V$ versus f_c

It can be seen that the evolution of $\dot{L}_V$ with f_c is an aleatory phenomenon as it is shown in figure 17. This is likely due to the momentary recovery of vital parameters by certain patients under medical treatment. Except when P_D is fixed because then a positive linear variation of $\dot{L}_V$ versus f_c is observed.

With respect to the weaker values of Δs observed, what to say? Just to repeat what has been already said for good comprehension.

Indeed for the healthy person or patient, as long he is still alive, it is said he lives in stationary state out of the thermodynamics equilibrium because the thermodynamics equilibrium state is a synonym of death (the heart stopping) [10]

To maintain this stationary state out of equilibrium the organism should, in order to offset the internal entropy production, dissipate the entropy through an exchange of heat and matter with its environment according to the exigency of thermodynamics second law ($\int dS = 0$; $\int d_i S = \int -d_o S$).

This is also evident for the system studied.

The internal entropy production $d_i S > 0$ originates from chemical reactions occurring in the organism, the external entropy dissipation $d_o S < 0$, beyond the heat dissipation, arises from the clear exportation of entropy by means of the matter exchange with outside.

This equality ($\int d_i S = \int -d_o S$) justifies the minus sign in the table I preceding the entropy variations values.

So it has been proposed for better understanding to consider Δs as a distance (not in physical sens) situating a heart from thermodynamics equilibrium state. As long as a heart is acting (health person or patient) $\int dS = 0$; $\int d_i S = \int -d_o S$ and $d_i S$ has a certain value. More

$d_i S$ is near the thermodynamics equilibrium, more the patient situation is unhealthy. Larger is this distance, better is the health. When $d_i S = -d_o S = dS = 0$, the ventricles contractions stopping can be observed, the heart stopping can be declared and thereby the patient physical death. The limits of these entropy variations are to be compulsorily calculated.

4. CONCLUSION

The overall purpose of this paper is to show that the cardiac exergetic yield depends only on differential pressure while $\dot{E}_V^+$ is depending **greatly** on cardiac frequency. As it can be observed indeed, in all these figures **KUNYIMA Equation** ($P_V = k_k P_D$) [6,7], **KUNYIMA formula** [5] and **KUNYIMA Relations** are indubitably verified for the sickle cell persons. The difference between the healthy persons and the sickle cell persons will be of course in the slopes of straight lines. The hypothesis according which all biological system which is not in transient state works at constant cardiac yield (P_D constant)[10,21] is confirmed and demonstrated like the Balmer empirical equation is nowadays demonstrated. Also an outstanding fact should be branded on memory: differential enthalpy is the total enthalpy accompanying the blood in its motion.

The apparition on world commercial market of new sphygmomanometer with further cardiac exergetic yield, cardiac power or volumic cardiac power is our eager desire [6,7].

The same paces of straight lines at healthy persons and at sickle cell anaemia women are observed except for the latters where the hazardous evolution of volumic density of exergetic loss in power as a function of cardiac frequency has been noted.

The content of this new research field called **Physical Cardiochemistry** will be submitted very soon at the international scientific world.

The relation between cardiac volumic yield and cardiac exergetic yield is searching in our laboratory. Also the relation between breathing frequency and cardiac frequency is the future preoccupation of our laboratory (LACOPA).

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