# OPTIMUM TIRE PRESSURE FOR LEGAL AXLE LOADS ON EGYPTIAN ROADS

## ضغط الإطار الأمثل لأحمال المحاور المسموح بها علي الطرق المصرية

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**الملخص العربي**

في السنوات الأخيرة، أصبح تأثير الحمل المحوري المتزايد للشاحنات على أداء الرصف موضوع ذو اهتمام عظيم في ظل السماح بزيادة حدود الحمل المحوري القانوني. لذا، تهدف هذه الدراسة إلى تحرى تأثير الحمل المحوري وضغط إطارات الشاحنات المتزايد على حياة الرصف بالنسبة للكلال والتخدد، للتعرف علي الضغط الأمثل للإطار الذي يناسب الحمل المحوري الموصى به في مصر للشاحنات. ولتحقيق هدف الدراسة تم استخدام عشر مستويات لحمل المحور تتراوح من ١٦ إلى ٣٤ ك باوند ومن ٢٠ إلى ٥٦ ك باوند للمحور المفرد والمحور المزدوج، على التوالي، مع عشر مستويات من ضغط الإطار؛ من ٨٠ الي١٧٠ رطل/البوصة المربعة. اعتمدت المنهجية المستخدمة في البحث على مفهوم تحليل الضرر والذي تم إجراؤه لكل من الكلال والتخدد باستخدام برنامج KENLAYER.

أوضحت نتائج الدراسة بأن حياة الرصف بالنسبة للتخدد تتعلق بشكل أساسي بمقدار الحمل المحوري، بينما حياة الرصف بالنسبة للكلال تتعلق بمقدار كل من ضغط الإطار وحمل المحور. أيضا، تتحقق الموازنة بين حياة الرصف بالنسبة للكلال والتخدد عند الحمل المحوري الثقيل مع ضغط الإطار العالي او عند الحمل المحوري الخفيف مع ضغط الإطار المنخفض. استنتجت الدراسة أيضا، أنّ الحمل المحوري الثقيل يجب أن يرتبط بضغط إطار عالي للاستفادة المثلي من مكونات الرصف. أخيرا، أوصت الدراسة بضغط إطار أمثل ١٤٠ و ١٢٠ رطل/البوصة المربعة للحمل المحوري المفرد والحمل المحوري المزدوج المسموح بهما في مصر، على التوالي.

**ABSTRACT**

In recent years, the effect of increased truck-axle load on pavement performance has become a subject of great concern under the allowance of increasing the limits of legal axle loads. So, the purpose of this study is to investigate the effect of increased truck-axle load and tire pressure on the pavement life with respect to fatigue and rutting, to recognize the optimum truck-tire pressure for the recommended truck-axle loads in Egypt. Ten axle loads levels ranging from 16-kip to 34-kip and from 20-kip to 56-kip for single and tandem axles, respectively, along with ten levels of tire contact pressure; 80-psi to 170-psi are investigated in this study. The used methodology is based on the damage analysis concept which performed for both fatigue cracking and rutting using KENLAYER program.

The study results showed that pavement life with respect to rutting is mainly related to the magnitude of the axle load, while fatigue life is mildly related to the magnitude of both tire pressure and axle load. Also, the equilibrium between fatigue and rutting lives is found at heavy axle loads associated with high tire pressure or at light axle loads associated with low tire pressure. The study also, concluded that the heavy axle load should associate with high tire pressure for optimum utilization of pavement section. Finally, the study recommended optimum truck-tire inflation pressure of 140 and 120-psi at the value of the legal axle load in Egypt for single axle and tandem axle, respectively.

**KEYWORDS:** Legal axle load, Tire pressure, Pavement life and KENLAYER program.

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## INTRODUCTION AND BACKGROUND

Truck traffic is considered one of the main inputs to any pavement design procedure. One principle of pavement design specifies that different axle loads, tire pressures and load configuration produce different stresses and strains in the various layers of a pavement structure [1].

One of the major trends, which assure saving in Vehicle Operating Cost is increasing truck-axle loads and truck-tire pressures [2, 3, 4]. So, over the past few years, many countries have increased the legal limits of truck-axle loads [5]. Many of United States has increased the legal axle load from 8-ton (18-kip) to 10-ton (22-kip), while in Europe, as French, the legal axle load has increased from 10-ton (22-kip) to 13-ton (28-kip). Also the legal truck-axle loads in Egypt were increased to 13-ton (28-kip) and 20-ton (44-kip), for single axle dual wheel and dual tandem axle, respectively [6, 7].

In recent years, decreased fatigue life, increased rutting, and accelerated serviceability loss in flexible pavements have been attributed to the effects of increased tire pressure [8]. That is, therefore a definite need to achieve the maximum utilization of the economic benefits of using high truck-tire pressure along with heavy truck-axle load in reasonably balanced design between the rutting and fatigue modes of distress.

So, the main objective of this study is to investigate the effects of truck-axle load as well as tire pressure on pavement life with respect to fatigue cracking and rutting using KENLAYER program. That is, to recognize the optimum truck-tire pressure for the legal axle loads, which achieve balanced pavement design in which, number of load repetitions to prevent fatigue cracking is the same as number of load repetitions to limit rutting.

Many researchers have used analytical methods to study of the effects of truck-tire pressure on pavement responses [9, 10, 11]. They found that tire pressure was significantly related to tensile strain; $\varepsilon_t$ at the bottom of the asphalt layer and stresses near the pavement surface for both the thick and thin pavements. However, tire pressure effects on vertical compressive strain; $\varepsilon_c$ at the top of the subgrade were minor, especially in the thick pavement. There are two major modes of distresses in which the pavement fails. Cracking of the surface layer and permanent deformation of the pavement system which manifests as rutting on the pavement surface. Damage analysis is performed for the two major modes of distresses as follows:

### Fatigue Criteria

The relationship between fatigue failure of asphalt concrete and tensile strain; $\varepsilon_t$ at the bottom of asphalt layer is represented by the number of repetitions as suggested by Asphalt Institute [12] in the following form:

$$N_f = 0.0796\,(1/\varepsilon_t)^{3.291}\,(1/E1)^{0.854} \qquad (1)$$

Where:

$N_f$ : number of load repetitions to prevent fatigue cracking.

$\varepsilon_t$ : tensile strain at the bottom of asphalt layer.

E1: elastic modulus of asphalt layer.

### Rutting Criteria

The relationship between rutting failure and compressive strain; $\varepsilon_c$ at the top of subgrade is represented by the number of load applications as suggested by Asphalt Institute [12] in the following form:

$$N_r = 1.365 * 10^{-9}\,(1/\varepsilon_c)^{4.477} \qquad (2)$$

Where:

$N_r$ : number of load applications to limit rutting.

$\varepsilon_c$ : vertical compressive strain, at the top of subgrade

## TYPICAL PAVEMENT SECTION

Flexible pavement is typically taken as a multi-layered elastic system in the analysis of pavement response. Materials in each layer are characterized by a modulus of elasticity (E) and a Poisson's ratio ($\mu$). Poisson's ratio; $\mu$ is considered as 0.35, 0.40 and 0.45 for asphalt layer, base course and subgrade, respectively. A typical cross section consists of asphalt layer thickness (4-in.) with elasticity modulus (400,000 psi), and base layer thickness (14-in) with elasticity modulus (25,000 psi), resting on subgrade with elasticity modulus (8,000 psi) is considered for analysis.

## INVESTIGATED AXLE LOADS AND TIRE PRESSURES

Different probable truck axle loads and tire pressures that may use Egyptian Roads are considered for analysis. Single axle loads are varied from 16 to 34-kip, while tandem axle loads are varied from 20 to 58–kip. Single axle loads are applied to the pavement on two sets of dual tires. The dual tires are approximated by two circular plates (with variable radius according to axle load and tire pressure) and spaced at 13.60-in. center to center. The tandem axles are represented by two axles spaced 54-in. center to center. The investigated contact pressure is varied from 80 psi to 170 psi.

Ten values of each axle load along with ten values of tire pressure are considered. The detrimental effects of this combination of axle loads and tire pressures on the pavement cross section are investigated by computing the tensile strain ($\varepsilon_t$) at the bottom of the asphalt layer and the compressive strain ($\varepsilon_c$) at the top of the subgrade by using computer program KENLAYER [13]. Then, damage analysis is performed using the two critical strains to compute pavement life for both fatigue cracking and permanent deformation. A circular tire imprint is assumed and the radius of contact is calculated as follow:

$$a = (\sqrt{P/\pi\, p_t}) \qquad (3)$$

Where:

a : Radius of contact.

P : Wheel load.

$P_t$ : Contact pressure.

## RESULTS AND DISSCUTION

The results of the damage analysis which performed on the typical cross section under the investigated axle loads and tire pressures using the KENLAYER program are presented in Figures (1 through 8) for both single axle-dual tire and dual tandem axel as follows.

**Single Axle –Dual Wheel**

Figure (1) shows the effect of axle load (P) with range from 16-kip to 34-kip for single axle along with tire pressure ($P_t$) with range from 80-psi to 170-psi, on pavement life with respect to fatigue ($N_f$) and rutting ($N_r$). It can be seen in the figure that both $N_r$ and $N_f$ decrease as P increases at all values of $P_t$. But, $N_r$ sharply decreases as P increase, compared with $N_f$ which is low sensitive to the variation of P. The effect of $P_t$ on pavement life at different axle loads is shown in Figure (2). The fact which can not be ignored that; $N_r$ has no sensitivity to the variation of tire pressure at all investigated values of P, while $N_f$ has moderate sensitivity to the variation of tire pressure. That is, it can be said that rutting life is mainly related to axle load, while fatigue life is mildly related to both tire pressure and axle load.

Referring to Figure (2), it can be also noticed that, the heavy the axle load the higher the tire pressure, to achieve equilibrium between $N_f$ and $N_r$ (balanced design), and vice versa. That is because, if heavy axle load is used with low tire pressure, the pavement will fail first in rutting. On the other hand, if light axle load is used with high tire pressure, the pavement will fail first in fatigue. So, to achieve balance between fatigue and rutting lives, it is preferable to use tire pressure for certain axle load, at which $N_f = N_r$ (i.e. at which the two curves intersect). This means from the technical point of view that, the heavy axle load should associate with high tire pressure for optimum utilization of pavement section. For opportunity, this coincides with the economical decision, that the higher the tire pressures the more saving in Vehicle Operating Cost. Examining Figures (1 and 2) at axle load of 13-ton (28-kip), it can be seen that the two curves intersect at contact pressure between 130 and 140 psi. It can be concluded that, at the value of the legal axle load in Egypt of 13-ton, the associated optimum tire inflation pressure is preferred to be 140-psi.

For pavement design purposes, a single value of pavement life (the smallest life between $N_f$ and $N_r$) should be considered as design life. So, the data in Figures (1 and 2) are assembled in Figures (3 and 4). Figure (3) shows the effect of axle loads on pavement design life at different levels of tire pressures. As shown in the Figure, the pavement design life sharply decreases as P increases, especially at low level of $P_t$ up to 130-psi, and the effect of $P_t$ terminates at P > 28-kip. This can be seen clearly in Figure (4), which shows the effect of tire pressures on pavement design life at different levels of axle loads. It can be seen in the figure that pavement design life mildly decreases with increasing $P_t$, especially at light axle loads up to 24-kip.

**Tandem Axle**

Figure (5 and 6) show the effect of interaction between axle load (P) with range from 20-kip to 56-kip for tandem axle along with tire pressure ($P_t$) with range from 80-psi to 170-psi, on pavement life with respect to fatigue ($N_f$) and rutting ($N_r$). Again, $N_r$ sharply decreases as P increase, compared with $N_f$ which is low sensitive to the variation of P, and $N_r$ has no sensitivity to the variation of tire pressure at all investigated values of P, while $N_f$ has moderate sensitivity to the variation of tire pressure. Also, rutting life is mainly related to tandem axle load, while fatigue life is mildly related to tire pressure and axle load.

Figure (6) shows that, the heavy the tandem axle load the higher the tire pressure, to achieve equilibrium between $N_f$ and $N_r$ as explained in previous section. Examining Figures (5 and 6), at tandem axle load of 20-ton (44-kip), it can be noticed that the two curves intersect at contact pressure between 110 and 120 psi. It can be also concluded that, at the value of the legal tandem axle load in Egypt of 20-ton (44-kip), the associated optimum inflation pressure is preferred to be 120-psi.

The data in Figures (5 and 6) are assembled in Figures (7, and 8). Figure (7) show the effect of tandem axle loads on pavement design life at different levels of tire pressures. As shown in the Figure, the pavement design life sharply decreases as P increases, especially at low level of $P_t$, and the effect of $P_t$ terminates at P > 52-kip. This can be seen clearly in Figure (6), which shows the effect of tire pressures on pavement design life at different levels of tandem axle loads. The figure shows that, pavement design life mildly decreases with increasing $P_t$, especially at light tandem axle loads up to 36-kip.

## CONCLUSIONS

Based on the methodology and analysis of results of this study, the following conclusions are drawn:

1. Increasing P decreases both $N_f$ and $N_r$, while increasing $P_t$ decreases $N_f$ only. .
2. Rutting is mainly related to axle load, while fatigue is moderately related to $P_t$, followed by P.

3. Pavement design life is related to axle load more than tire pressure.

4. The heavy the axle load the higher the tire pressure, to achieve equilibrium between $N_f$ and $N_r$ (balanced design), and vice versa.

5. The equilibrium between fatigue and rutting lives is found at heavy axle loads associated with high tire pressure or at light axle loads associated with low tire pressure.

6. High tire pressure should associate with the heavy axle load for maximum saving in Vehicle Operating Costs.

7. It is recommended to allow for truck-tire inflation pressure as high as 140, and 120-psi, along with the legal axle loads in Egypt (13-ton and 20-ton) for single axle and tandem axle, respectively for optimum utilization of pavement section

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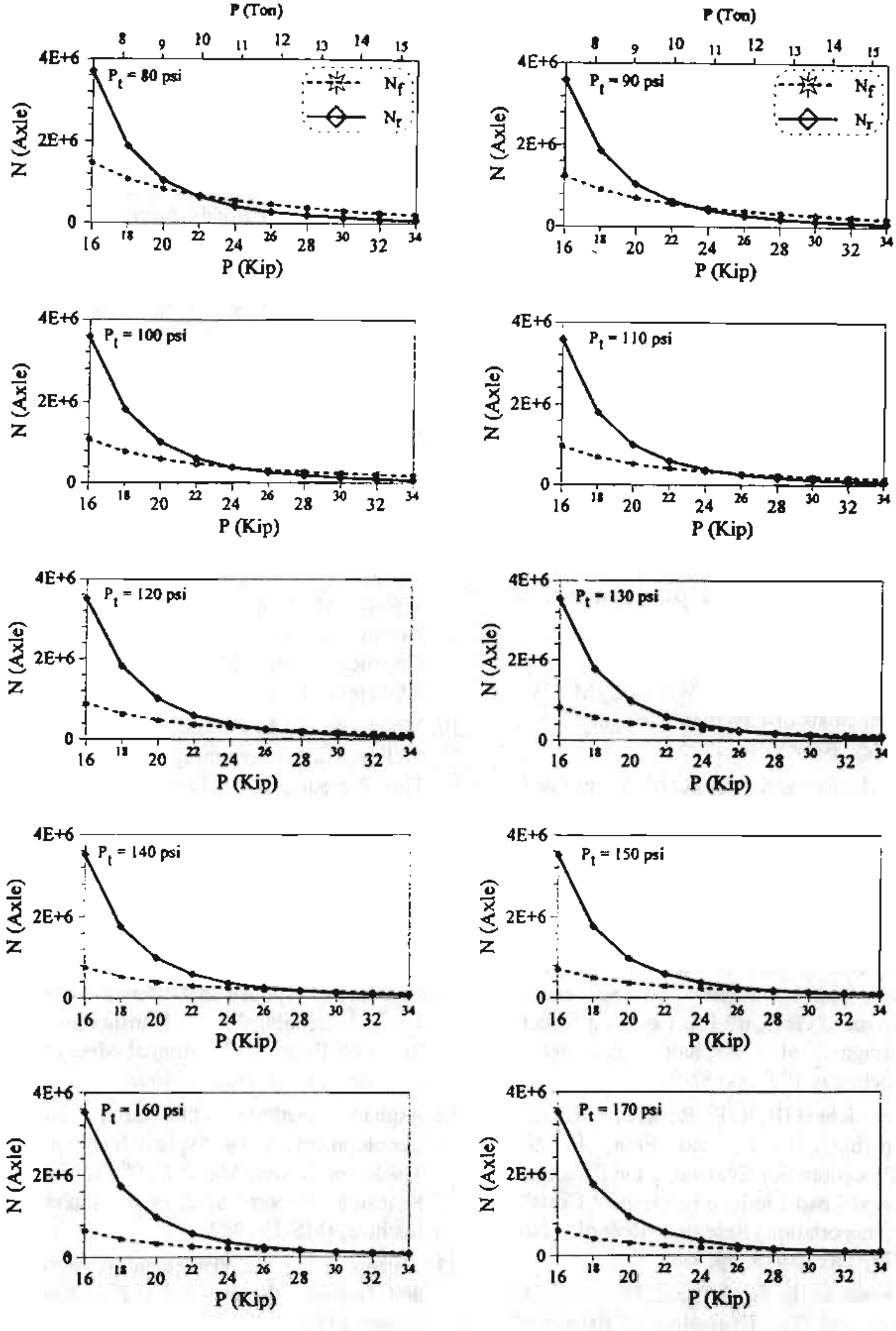


**Figure 1: Effect of axle load on pavement life at different tire pressures (Single axle-dual Wheel)**

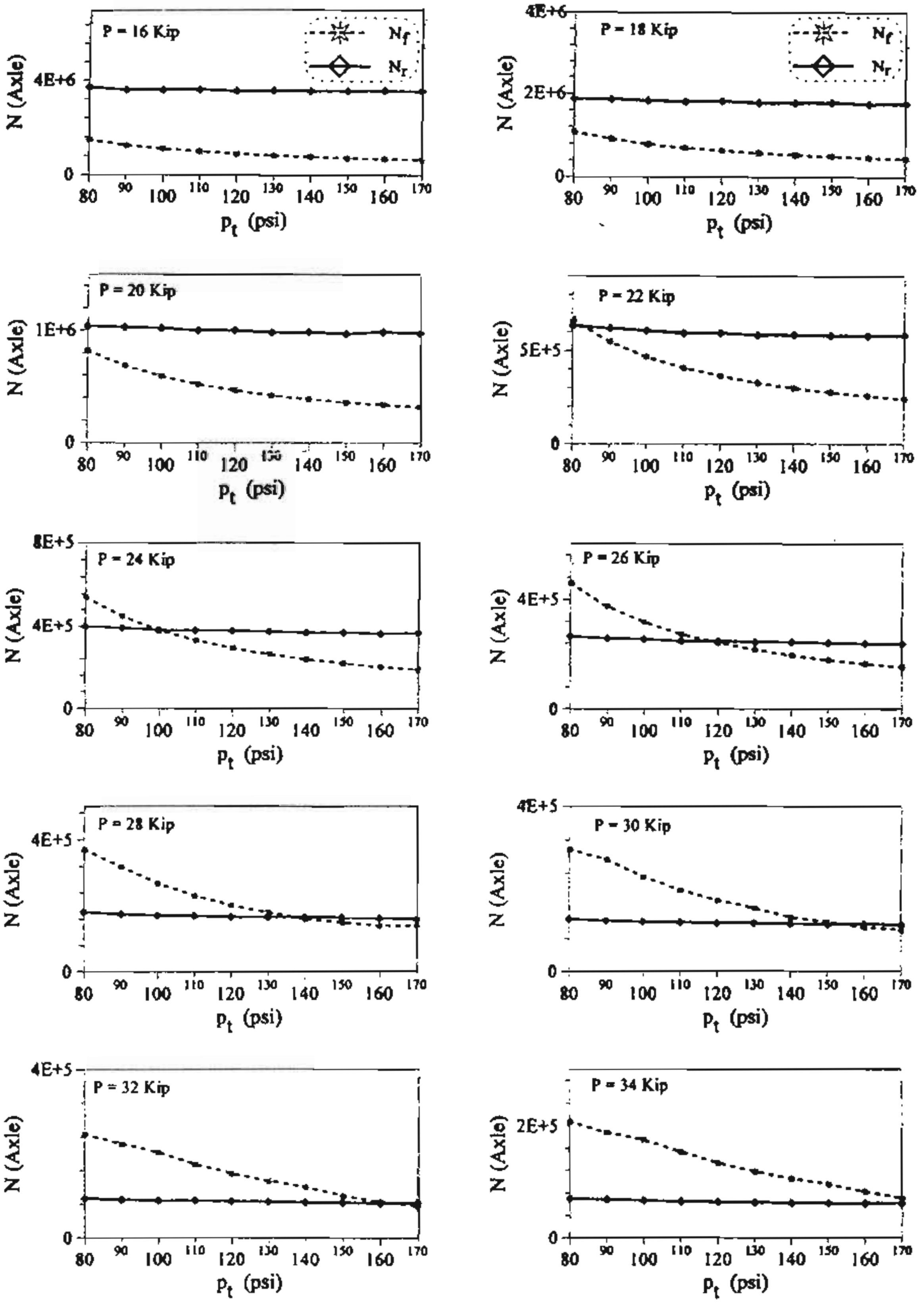


**Figure 2: Effect of tire pressure on pavement life at different Axle loads (Single axle-dual wheel)**

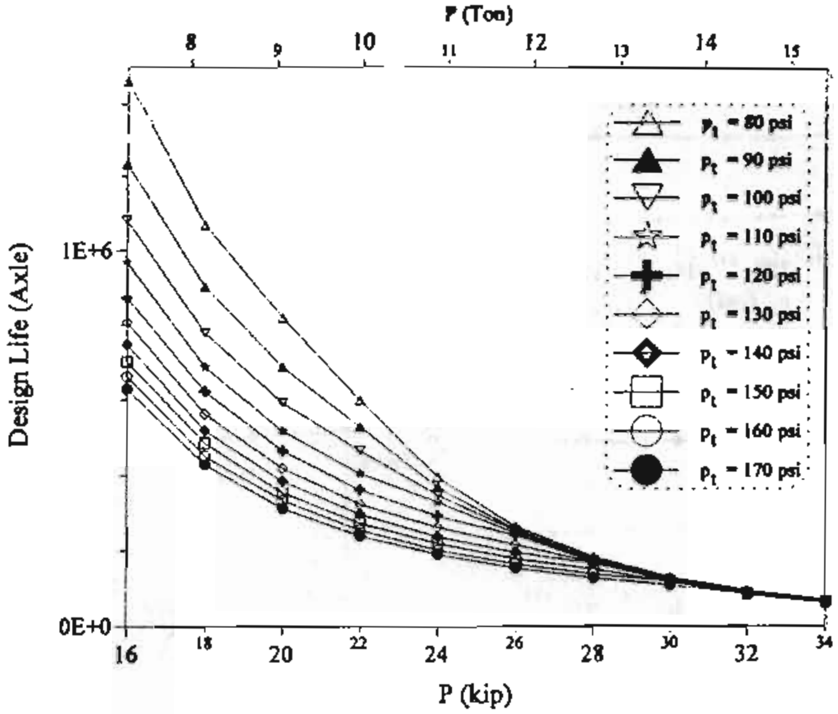


Figure 3: Effect of axle load on design life at different tire pressures (single axle-dual wheel)

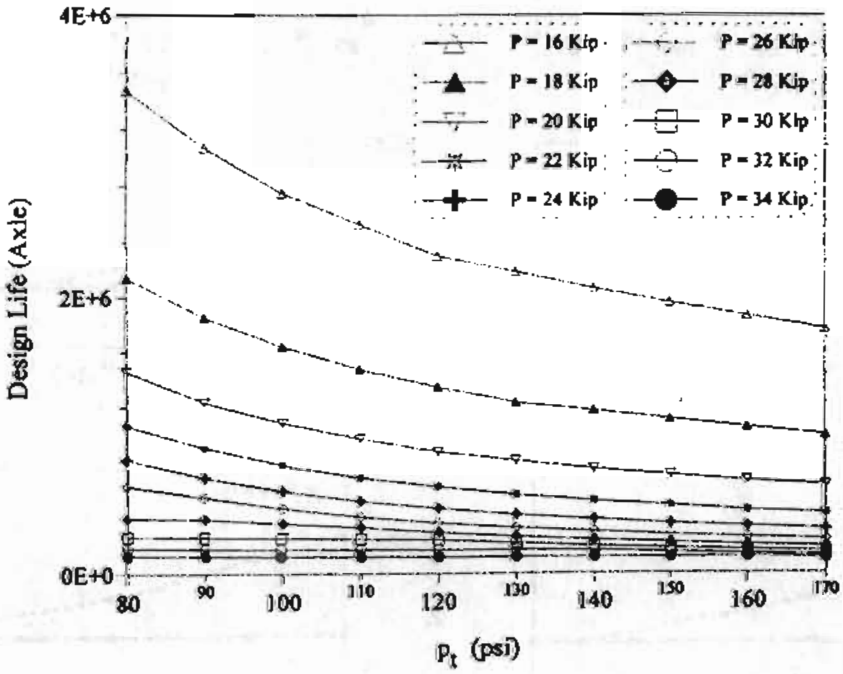


Figure 4: Effect of tire pressure on design life at different axle loads (single axle-dual wheel)

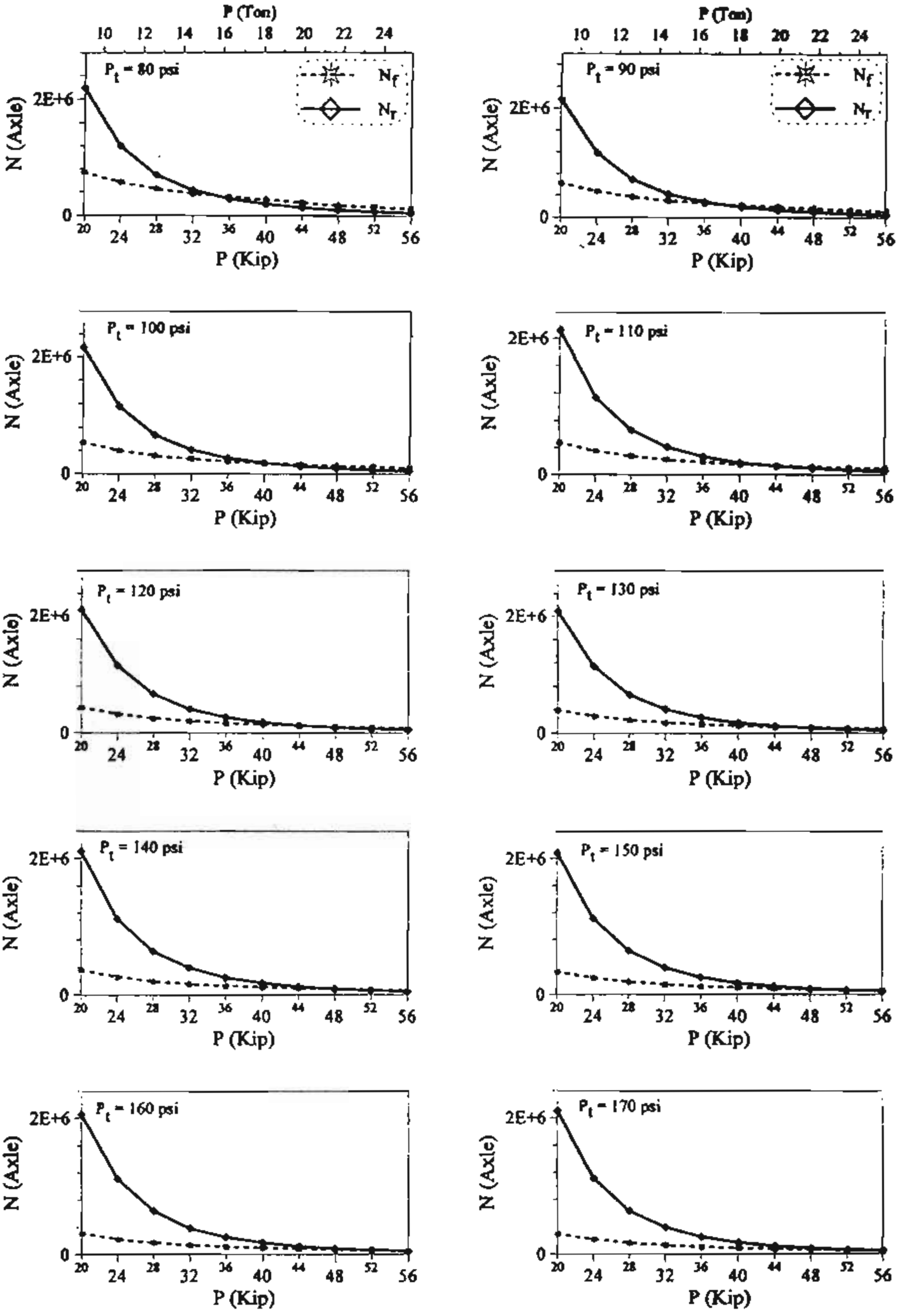


**Figure 5: Effect of axle load on pavement life at different tire pressures (Tandem Axle)**

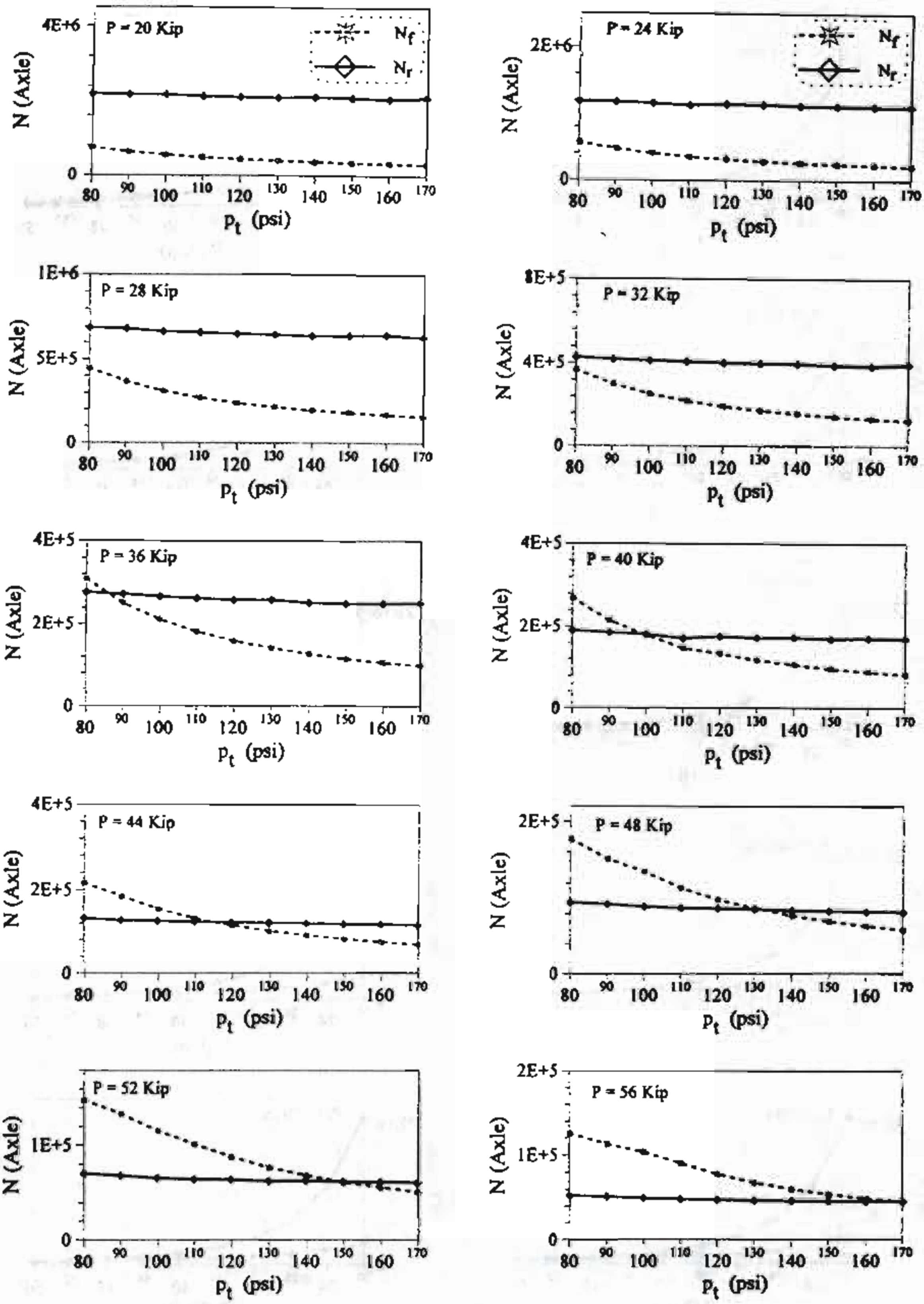


**Figure 6: Effect of tire pressure on pavement life at different axle loads (Tandem Axle)**

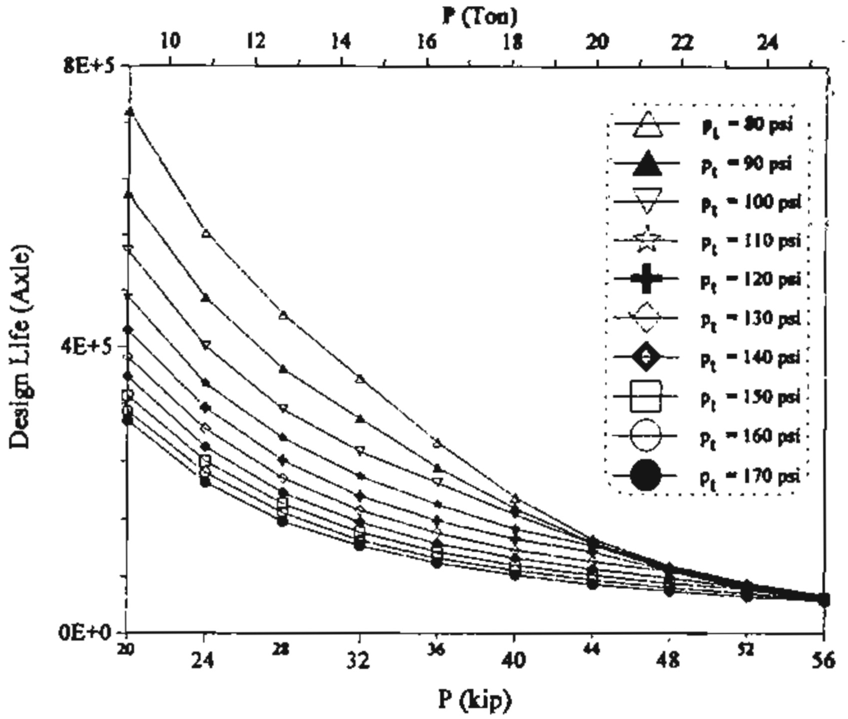


Figure 7: Effect of axle load on design life at different tire pressures (Tandem Axle)

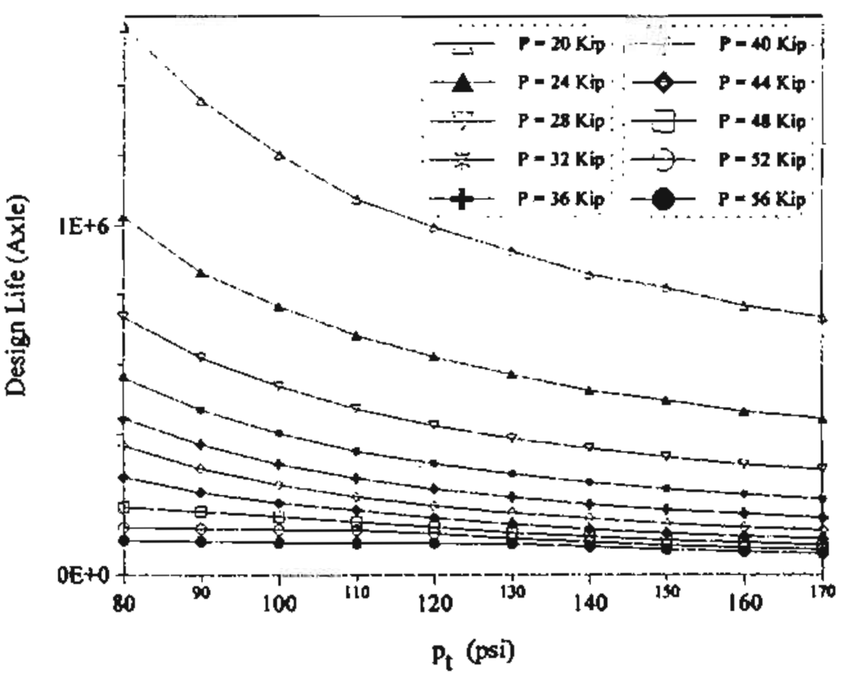


Figure 8: Effect of tire pressure on design life at different axle loads (Tandem Axel)